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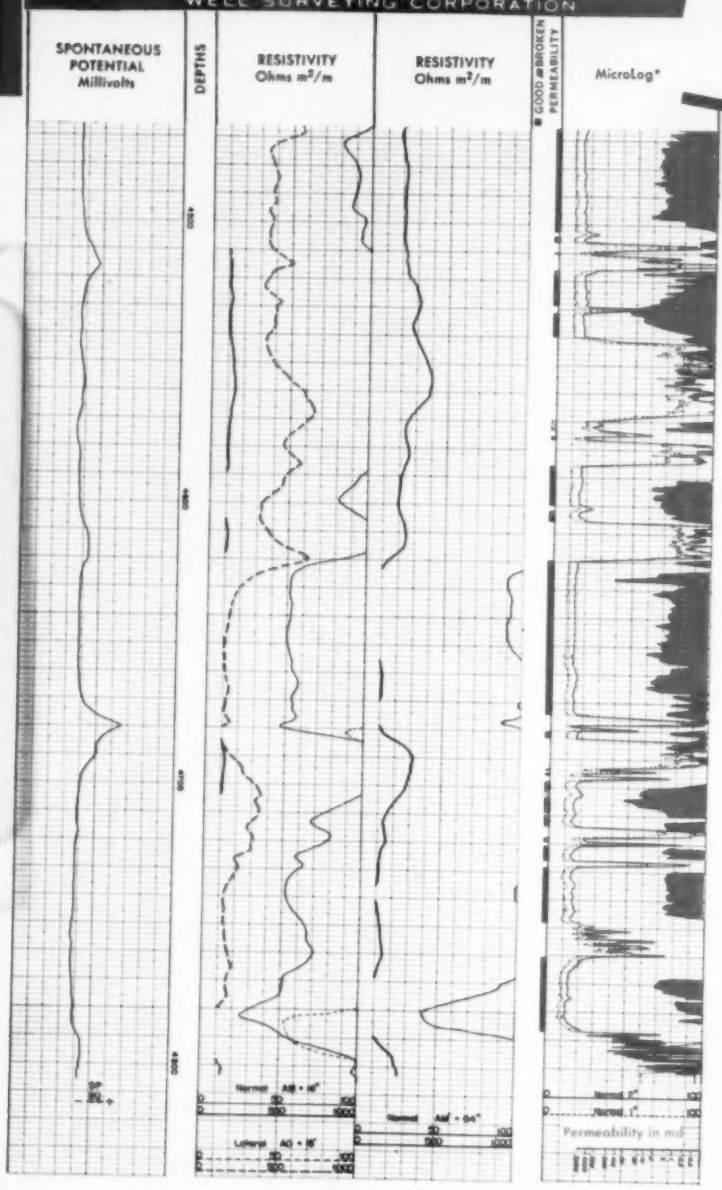
REEF LIMESTONE IN ROUND TOP FIELD FISHER COUNTY, TEXAS



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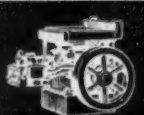
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Additional entry at Dallas, Texas

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Only through the effective centering of your casing in the open hole can you obtain a sufficiently uniform annular cementing space to permit distribution of the cement slurry completely around the casing. Under this condition the hazard of channeling is minimized, and the best opportunity for success of the installation is present.

When you run a Baker Model "G" Casing Centralizer you can rest assured that it will do a proper centering job. You need no longer worry about trial-and-error centering of your casing, because the Baker Centralizer is a proven centralizer with many exclusive as well as desirable features:

1. It exerts maximum centering force where it is needed—not as the centralizer first enters the well bore, or above the first well constriction, but after the most rugged trip to the bottom of the hole, at the point where the actual centering job must be done.

2. Its springs are designed on the basis of maximum spring centralizing efficiency alone, without any interference from complicating factors.

3. Its springs are *never* forced to deflect over the sharp edge of a ring or collar, since they are *butt-welded* (not lap-welded or riveted) to the Spring Collars; and the Stop Rings are positioned safely *outside* of the spring assembly area. Thus the casing supports the total centering force by direct contact with the springs.

4. As its springs deflect, their active length decreases. They are thereby stiffened and their centralizing action is increased.

5. All of its springs are compressed simultaneously as a unit and cannot be deflected individually.

6. Its mounting design permits rotation of the casing even under adverse conditions, and within annular clearances smaller than can be approached by any other centralizer.

7. It is, in effect, scientifically "tailor-made" to produce optimum characteristics for each individual casing range.

8. It starts easily, and the Baker "tailor-made" feature eliminates the need for snubbing.

9. It is easy to install on the pipe. No on-the-job sizing or adjusting is required. Everything is pre-positioned so that the unit may be merely slipped on the casing and welded in place.

10. It is always PULLED (never pushed) as it is run-in the hole. This averts the danger of distorting or otherwise damaging the springs while raising or lowering the casing string past restrictions in the hole.

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Answer each question by writing "Yes" or "No" in the blank spaces in the column at right

Here are the FACTS you need to know		BAKER Casing Centralizer	Any Other Centralizer
1	Is the centralizer so designed and mounted that the "load point" is imposed directly upon the casing?	YES	
2	Do all of the springs compress simultaneously and move freely along the smooth surface of the casing?	YES	
3	Are the springs butt-welded to the spring collar so that they never are forced to deflect over a ring or collar?	YES	
4	Is it a quick and easy matter to determine the minimum spacing of centralizers without having to "snub-in" the first few joints of casing?	YES	
5	Is the assembled centralizer pre-positioned so that it can merely be slipped on the casing and welded in place, without any on-the-job sizing or adjusting?	YES	
6	Can the springs be completely flattened several times as they pass tight spots or "dog legs," without losing a large percentage of their centering efficiency?	YES	
7	Can the casing be rotated—without rotating the centralizer—in smaller annular clearances than is possible with any other centering device?	YES	
8	Are you ready to listen to "easy-to-believe" scientific facts which will convince you that only the Baker Model "G" Casing Centralizer exerts maximum centering force at the cementing point after a rugged trip past tight spots and dog legs?	Ask any Baker representative	

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Editorial Comment

By John E. Sherborne

Branch Chairman

A Tribute . . . For Outstanding Service

WHEN one accepts election or appointment to office, whether it be as a paid employee, a public servant, a volunteer participant in civic affairs, or as a member of a professional organization such as the American Institute of Mining and Metallurgical Engineers, it is axiomatic that in so doing he assumes a responsibility which his associates have a right to expect he will discharge as effectively as possible. How successfully he will accomplish the requirements of his post will depend upon a number of factors each of which, in itself, may exert a controlling influence.

Besides ability, conscientiousness, and integrity, which it seems reasonable to expect the individual will have, such items as appreciation of the problems to be solved, a desire to accomplish their solution, a substantial interest in the duties of the post relative to other interests, and freedom and time to devote to the duties of the office appear to be significant. Seldom under present day business conditions, when men of executive ability generally have a multiplicity of interests and an almost overwhelming demand upon their time, are conditions favorable for an optimum interplay of the several items. As a consequence, no matter what his ability may be nor the degree of his interest, it is normally only possible for an individual to fulfill the requirements of office to the extent of doing a good job within "the call of duty."

IN all respects, the year 1949 was a year of outstanding achievement for the Petroleum Branch. It was a year which saw the initiation of the branch publication, the JOURNAL OF PETROLEUM TECHNOLOGY, an organ which is a credit to those immediately concerned with its publication, the Branch, the Institute, and the industry. It was a period in which numerous steps were taken to improve the financial status of the Branch. It was a time of adoption of the branch structure by the Institute and recognition of its advantages. It was a year of increased interest in the Petroleum Branch as evidenced by the large number of applicants for membership. A more detailed evaluation of the progress made during the year was presented in the editorial of the February issue of the JOURNAL.

To a large extent, the success of the Branch for 1949 was the result of outstanding leadership of your chairman for that period, Lloyd E. Elkins. The Branch was indeed fortunate in having in Lloyd a man who was not only willing and able, but who had sufficient interest in and was in a position to vigorously attack the duties of his office. It should be of interest to all members, that during this past year, when it was of the utmost importance that the opinions, desires, and needs of the members of the Petroleum Branch be brought before officers and directors of the Institute, Lloyd attended seven of the eight meetings of the Board of Directors of the Institute. All of these were about as far away from Tulsa, Lloyd's home, as could be. All but one meeting was held in New York. The other was held in San Francisco.

In recognition of his efforts, the Executive Committee of the Petroleum Branch has passed the following resolution:

Whereas, the year 1949 has been one of outstanding achievement for the Petroleum Branch, and

Whereas, this achievement has been made possible to a large extent as a result of the keen interest in, and untiring efforts on behalf of the Petroleum Branch by your Branch chairman for 1949, and

Whereas, by his administrative ability and infectious good comradeship he has welded the Branch membership into an effective and coordinated unit, and

Whereas, he has devoted his energy and time to Petroleum Branch affairs to an extent far and above that required for the normal fulfillment of the duties of office, and

Whereas, he has at every opportunity perspiaciously acquainted the officers and Board of Directors of the Institute with the opinions, desires, needs and activities of the members of the Petroleum Branch, and

Whereas, his efforts have been an inspiration and stimulant to all of those having had the good fortune to work with him in Branch activities.

HEREBY be it resolved, that on behalf of the executive committee and the members of the Petroleum Branch, a vote of deep appreciation be accorded Lloyd E. Elkins for his outstanding service to the Petroleum Branch and the Institute as chairman of the Branch for 1949. ★ ★ ★

DONALD H. McLAUGHLIN

AIME

President

1950

To the mining industry Homestake and Cerro de Pasco are as well known as Chevrolet and Ford are to the car industry. The mining man connects certain names with the history and development of these two companies as readily as the industry recalls the records of the various car models. One name closely associated with the more recent history of both companies is that of Donald Hamilton McLaughlin, president of the AIME for 1950.

It is a generally well-known fact that Pres. McLaughlin became head of the Cerro de Pasco Copper Corp.'s geological department at an unusually youthful age — he hadn't completed his twenties. It is also common knowledge that Cerro de Pasco's geological department became one of the largest of any mining company. So it is evident he had a full-time job supervising exploration and development programs of the corporation's extensive copper, silver and coal deposits in various parts of Peru. As one of the first American engineers to do extensive work in South America, he ranks as a pioneer in a real Pan American movement.

WHEN he went to Harvard in 1925 as professor of mining engineering and geology, he became one of the youngest professors in the history of the university. Our new president was born in San Francisco Dec. 15, 1891, graduated from the University of California in 1914, and received his doctor's degree in geology from Harvard in 1917. For the next two years he was addressed as "Lieutenant" in view of his affiliation with the 63rd Infantry, United States Army. Donning familiar clothing again, the young engineer went to Peru in 1920.

While at Harvard, Pres. McLaughlin became chairman of the Division of Geological Sciences and of the Department of Geology and Geography. In addition to his academic duties, he maintained his interest in the field as a consultant, his principal client being the Homestake Mining Co. That company was incorporated in California a good many years before Pres. McLaughlin put in his appearance there, but by the time he had acquired a consultant's background he was able to help solve certain geological problems at Homestake. Those solutions were of considerable value both in control of grade and in the development of additional reserves of ore.

The lure of California called him in 1941 and back he went to become dean of the College of Engineering at his alma mater, the University of California. Big business claimed him two years later when he was made vice-president and director of Cerro de Pasco. Sandwiched in along the way were activities that kept him busy as chairman of the Advisory Committee on Raw Materials of the Atomic Energy Commission, chairman of the National Minerals Advisory Council and a member of the task force on natural resources of the Hoover Commission. He is a director of the American Trust Co., the Empire Trust Co., The Bunker Hill and Sullivan Mining and Concentrating Co., The Dorr Co., the International Nickel Co. of Canada, San Luis Mining Co. and Triumph Mining Co.

SUCH activity, however, has not prevented Pres. McLaughlin from finding time to be chairman of the first AIME Committee on Geophysics and to have a hand in getting out the outstanding Geophysical Prospecting volume in 1929. In addition, he has served as chairman of the Mining Geology Committee and as a member of the Papers and Publications Committee and was a member of the Committee on the Lindgren Volume, Ore Deposits of the Western States. In 1947 he was a vice-president of the AIME. ★ ★ ★

PAUL ANDREWS

Petroleum Branch

Vice Chairman

1950

AN appellation he frequently uses in talking about someone else can be used with considerable accuracy in talking about Paul Andrews — "There's a fine gentleman." You only have to spend a few minutes with him to come under the spell of his personal charm and to get in the clutches of his friendship. As your acquaintance progresses you find out that he is a native Texan, having been born in Henrietta, Texas, near Wichita Falls, but is now a converted Californian living in Los Angeles.

He moved with his family to Salt Lake City at an early age and attended public schools there. He started working while still a boy, and after graduation from high school entered the University of Utah to study mining engineering. This led him to try his hand at mining, so he leased a tract near Eureka, Utah, and started digging for silver. There he learned to crimp caps with his teeth, which qualified him as a hard-rock miner. The result is that when he comes in contact now with the proverbial controversy between the miners and the petroleum people as to who can consume the most hard liquid, he claims credentials to participate on both sides.

A strong ambition pushed him to San Francisco, and then on to Long Beach in 1926, where he affiliated with the Standard Gasoline Corp. as a test and natural gas engineer. In addition to his work he attended the University of Southern California, studying petroleum engineering. He left Standard to join the Italio Petroleum Co., then joined the Signal Oil & Gas Co. in Los Angeles in 1930 as a production engineer.

HIS business life since has been with Signal. He helped pioneer the gas lift by using the dry gas from Signal Hill to increase production there. In 1935 he was sent to Elwood, California, to work in production engineering, and while there made an extensive survey of instruments and systems used for increasing the efficiency of producing wells. This resulted in the purchase of a battery of pressure bombs and other instruments for determining bottom hole conditions. The whole project resulted in his organizing a production engineering department for Signal in 1938, and in his elevation to chief production engineer for the company.

Miss Mina Olson, a native of Kansas, became Mrs. Andrews in 1935. In spite of their two charming daughters, Paula, 9, and Patricia, 7, she joins Paul in many activities; and her presence has been a definite contribution to the enjoyment of quite a few AIME meetings.

Possessing quite a reputation as a raconteur, our friend will offer to exchange stories with you at the drop of a hat. He picked up a couple of stories with a slight Spanish accent just before the Los Angeles Branch meeting last year, and before the meeting was over he almost had the authors delivering their papers in a Spanish dialect. He is a good impromptu speaker, an excellent host, and takes endless color photos of his daughters which he will show you on the slightest provocation. He is an ardent surf fisherman, but is the crazy type that stays out all night with a Coleman lantern searching for a fish. Those who have spent some money finding out say that he plays strictly an unorthodox brand of poker.

IN addition to his work with Signal, Paul has served the industry well in quite a number of assignments in the CCCOP, the API, and the AIME. He held the national chairmanship of the API Topical Committee on Production Practice during the last year, and at the same time was chairman of the Pacific Petroleum Chapter of AIME, as well as a member of the Executive Committee of the Petroleum Branch. He takes a personal interest in all phases of our activity, and his year as vice-chairman of the Branch will prove of much benefit to the Society. ★ ★ ★

THE APPLICATION OF THE MARKET DEMAND STATUTE TO OIL PRODUCTION IN TEXAS

ERNEST O. THOMPSON, COMMISSIONER,

TEXAS RAILROAD COMMISSION

Twice in a generation this nation has had to depend on oil for its security in war. Each time found us ready with the needed oil. This ready reserve of oil did not just happen. It is the fruit of conservation, to which your profession has greatly contributed.

The Texas Railroad Commission is the oil and gas regulatory authority in the State of Texas. It may seem odd that the name should be Railroad Commission from the oil and gas standpoint.

We, of course, have our Oil and Gas Division of our Commission that is staffed with petroleum engineers. We hold about 10 hearings a day on oil and gas conservation and production matters. The record is transcribed and presented to the Commissioners for decision. The engineers and examiners sit in executive conference with the Commission and enter freely into the discussions when the cases are considered. Then and there the Commissioners vote and decide each case on the merits.

This system is upheld uniformly by our courts and is well accepted by the industry and the public. The enormity of the task is indicated when it is noted that there are 1,700 separate oil fields with 117,172 producing oil wells in Texas today.

Each field presents a separate problem. These problems touch upon and deal with matters of geography, geology, physics, law, and engineering. Indeed the orders on oil and gas production vitally affect the economy and welfare of our country.

In the case of Rowan and Nichols which involved the method of oil allowable allocation in the giant East Texas field, the Supreme Court in upholding our orders said, "Underlying these claims (of the various interests) is as thorny a problem as has challenged the ingenuity of legislatures." In promulgating these orders we act in a legislative capacity, under standards set up in the law.

This article was presented at the AIME Annual Meeting in New York City, February 13-17, 1950.

Statute Defines Production Waste

The Texas laws define waste in connection with the production of oil and gas as follows:

"ART. 6014. *Waste*

The production, storage or transportation of crude petroleum oil or of natural gas in such manner, in such amount, or under such conditions as to constitute waste is hereby declared to be unlawful and is prohibited. The term "waste" among other things shall specifically include:

(a) The operation of any oil well or wells with an inefficient gas-oil ratio, and the Commission is hereby given authority to fix and determine by order such ratio; provided that the utilization for manufacture of natural gasoline of gas produced from an oil well within the permitted gas-oil ratio shall not be included within the definition of waste.

(b) The drowning with water of any stratum or part thereof capable of producing oil or gas, or both oil and gas, in paying quantities.

(c) Underground waste or loss however caused and whether or not defined in other subdivisions hereof.

(d) Permitting any natural gas well to burn wastefully.

(e) The creation of unnecessary fire hazards.

(f) Physical waste or loss incident to, or resulting from, so drilling, equipping, locating, spacing or operating well or wells as to reduce or tend to reduce the total ultimate recovery of crude petroleum oil or natural gas from any pool.

(g) Waste or loss incident to, or resulting from, the unnecessary, inefficient, excessive or improper use of the reservoir energy, including the gas energy or water drive, in any well or pool; however, it is not the intent of this Act to require repressuring of an oil pool or that the separately owned properties in any pool be unitized under one management, control or ownership.

(h) Surface waste or surface loss, including the storage either permanent or temporary of crude petroleum oil, or the placing any product thereof, in open pits or earthen storage, and all other forms of surface waste or surface loss, including unnecessary or excessive surface losses, or destruction without beneficial use, either of crude petroleum oil or of natural gas.

(i) The escape into the open air, from a well producing both oil and gas, of natural gas in excess of the amount which is necessary in the efficient drilling or operation of the well.

(j) The production of crude petroleum oil in excess of transportation or market facilities or reasonable market demand. The Commission may determine when such excess production exists or is imminent and ascertain the reasonable market demand.

The Commission may consider any or all of the above definitions, whenever the facts, circumstances or conditions make them applicable, in making rules, regulations or orders to prevent waste of oil or gas.

Allocation of Market

The regulation starts with providing rules for proper spacing of wells before drilling, testing of casing, protection against blowouts, protection of fresh water encountered in drilling, and then when oil or gas is found we test the wells and set a proper allowable for the wells and the fields so that the reservoir energy will be utilized in the highest degree and then, above all, when the ability to produce oil or gas is greater than the market demand, we allocate the market fairly to each of the 1700 oil fields and then distribute the fields' allowables among the 117,000 producing wells of the State so that every field and every well in each field has the opportunity to share ratably in the market demand for Texas oil.

It has been a process of evolution — a process of trial and error and constant testing in the courts of the land. We have had cases in all the courts, including several in the United States Supreme Court.

In the beginning, we lost cases in the trial and error process, but today our orders stand sustained by all of the courts. As equally important, these orders have also been sustained by an enlightened public opinion. The public is now more than ever sensitive to waste in any form. You hear every day about waste of water, soil, and oil.

Lately, within the last year, it was ordered that oil producers must save the gas produced with the oil or cease producing the oil.

These orders were issued after repeated warnings to the operators, and as a result finally of show cause orders in each field. They resulted in sixteen lawsuits being filed against the Commission seeking to restrain and enjoin the Commission from enforcing these gas-saving orders. So far fourteen of these cases have come to final decision, and we have won all fourteen of them.

There is no difference in the two cases yet to be decided.

This action has resulted in the saving for use billions of cubic feet of gas formerly burned in flares at the oil wells. The day of the oil well flare is gone in Texas. That is wherever the quantity of gas is sufficient to make the gathering of it economically feasible. Of course, there will always be instances where the quantity of gas produced with the oil is so small it would be unreasonable to require it to be gathered and saved.

This brings the discussion to its main point — "The Application of the Market Demand Statute to Oil Production in Texas."

Consideration of Market Demand

The Texas law requires that the Railroad Commission of Texas consider market demand in setting the allowable production in Texas. The present law (1) prohibits the waste of oil; (2) defines waste as including the production of oil in excess of transportation or market facilities or reasonable market demand; (3) authorizes the Commission to determine when production is in excess of market demand; (4) gives the Commission power to limit the production of oil; (5) prorates allowable production; (6) and makes and enforces rules, regulations, and orders necessary for the exercise of these powers. (7) The Statute sets out in detail the powers and duties of the Commission relative to its determination of market demand, the existence of waste, and its promulgation of orders.

Prior to the enactment of the present market demand Statute, the Statute in force made no provision for prorating production to market demand. At that time, the Commission attempted to prorate the production to market demand in the East Texas field.

A three-judge federal court enjoined the enforcement of the Commission's orders on the ground that the authority to make and enforce said orders had not been delegated to the Commission by Statute. In addition, the court said that in the absence of tests and experiments to demonstrate the orders effective to prevent waste, they could be considered nothing more than an attempt to prorate production on the basis of market demand for the purpose of raising prices of crude oil and the prevention of economic waste and as an exercise of powers either not granted or plainly denied to the Commission.

The conservation act was again amended even before the injunction in the above case was issued. This new act authorized the proration of oil and gas production on the basis of market demand. Proration orders were issued under the new act for the Panhandle field. The new act was tested in federal court where the contention that the limitation of production demand was an unwarranted interference with property rights and was an attempt to fix prices rather than to restrain waste was overruled.

The Court held the Statute and the orders valid because the order complied with the Statute in apportioning the allowable among the producers in the field and because the orders were not unreasonable and not arbitrary.

Again during the period of falling prices and extreme overproduction, the Commission reduced the East Texas allowable. In fixing the market demand allowable, the Commission used the same estimated requirements given out by the Bureau of Mines. The orders were attacked on the same grounds as before plus the ground that the Commission had abdicated its authority to the federal government. A three-judge court upheld the Statute and the order. The majority of the court

was convinced that an allowable set by Commission order was necessary to prevent waste.

With the authority granted by the Texas Statutes, the Commission each month ascertains the market demand and then allocates ratably and fairly to each of the field of the State that field's proper proportion of the market demand for crude for the ensuing month, and then the oil that is allocated to each particular field is, in turn, prorated among the wells of that particular field under a formula which has been arrived at in each field by evidence advanced at a hearing called for that purpose, at which the operators, with their engineers, show the Commission by sworn testimony how best fairly to prorate the oil among the wells of the field.

This process has worked so well in practice that there are no unconnected wells in the State of Texas where the distance to major pipe lines is not so great for the amount of oil available, and even in the rare instances where there is no pipe line, there is market for the oil from these unconnected wells by truck to a pipe line.

Fair Distribution a Problem

This was one of the major problems in conservation of oil; namely, to give each well its fair share of the market so that every producer, large and small alike, could have some outlet each day for his oil as it was produced.

Under this method since the law was passed, Texas market demand has increased steadily from 870,000 barrels per day to around 2,000,000 barrels per day, and we have had a healthy, expanding, profitable oil producing industry in Texas.

The method of operation can best be shown by example. The winter of 1948-49 proved to be exceedingly mild and accumulated stocks did not move out for heating purposes as was normally expected. The buyers of crude were demanding that less crude be produced and were telling us in open hearings called for the purpose each month, that unless production were reduced, they would be compelled to prorate their pipe line take.

In other words, they would not buy, and oil producers do not keep oil on hand, and in fact, they have no facilities for keeping oil on hand. The producers simply have stock-tank facilities on their leases to handle current production. They depend upon the pipe line buyers to take their oil daily as produced.

The Railroad Commission of Texas, according to evidence which we took each month, successively reduced the allowable in Texas each and every month from January until August, 1949, always supplying all the oil that anyone would buy, provided the spread is ratable. It must be remembered that the buyers of crude always would prefer to buy from those fields in which they themselves have major interests or they prefer to buy from those fields in which they have nearby refineries or from those fields which give them the most desirable crude from a refining standpoint.

This is called selective buying, which, if permitted, would give all the market to certain fields and leave other fields with no market at all, which would not be legal — it would not be fair proration. The Railroad Commission of Texas has insisted that the buyers spread their demands over the entire State so that every oil field in Texas can share ratably in the market demand.

The allowable production for the State of Texas is about 2,000,000 barrels per day. The United States' production is in the nature of 5,000,000 barrels per day.

Texas is permitting the operation of her wells only 15 days per month for all the fields of the State, except the East Texas field which is allowed to operate only 13 days in the month.

This shutdown for almost one-half the time is caused solely on account of the lack of market demand for crude oil. If we had the market, Texas could easily produce an additional million barrels of oil per day without harm to the wells or to the reservoirs.

Now in the few short years since the close of World War II we have again rebuilt oil-producing reserves to a point where we can safely supply without waste an additional million barrels of oil per day if, when, and as needed.

How To Arrive at Market Demand

The question naturally arises -- how do we arrive at market demand? In the first place, market demand for Texas oil is but a part of the over-all demand. Recognizing this, the Commission periodically holds hearings for the specific purpose of ascertaining what is the proper amount of crude oil necessary to insure refineries adequate working stocks. At the last such inquiry made at our hearing at Houston, Texas, on April 19, 1949, the testimony was that the required stocks of crude oil and gasoline for the United States in order to have an ample workable supply were as follows:

	Opinion of Required Crude Stocks	*Same on Gasoline*	
		April 1	*Oct. 1*
Texas Company	250-range 225-275	120	88
Gulf	265	125	95
Tide Water	250	120	95
Humble	248-268	122-127	89-94
Sun	240-268	128	110 (Nov. 1)
Socony	250-268	120	93
Atlantic	240	120-125	85-90
Standard Ind.	250-260	123	95
Shell	250-275	128	
Cities Service	250-260	123-126	93-95
Sinclair	268	127	
Continental	255-285	130	100
Phillips	245		94
Skelly	250	125	90

Crude stocks in the United States on January 14, 1950, stood at 249,487,000 barrels. It will be seen that they are adequate but still not too high.

Gasoline stocks on the same date were 118,844,000 barrels. Here it will be seen that gasoline in January is nearly at the 120,000,000 barrels testified as being ample for April 1, the beginning of the heavy consuming season.

At the close of the war crude stocks were down to 211,000,000 barrels. Thereafter, we began to build up stocks quite speedily.

We increased crude stocks 280,000 barrels per day during 1948 until in December, 1948, it became clear to our Commission, and we were about the first to realize it and to do something about it by drastically reducing Texas' allowable production for January, 1949, and cut production each succeeding month for nine consecutive months.

There have been those who suggested that the regulatory bodies adhere to the Bureau of Mines forecast of market demand. Some have claimed that the oil-producing states are slaves to the estimates of demand put out by the Bureau. Such is not and has never been the case.

The Bureau of Mines estimate of crude demand is exactly like the report put out by the Weather Bureau each day about what they think the weather is going to be like. If they say "rain" and you do not believe it, the weather man does not mind whether you get wet and you don't blame the Weather Bureau.

It's exactly like the reports the Department of Agriculture puts out on crop forecasts. It's an informed estimate or guess on what the best data obtainable indicates.

These Bureau of Mines forecasts of crude demand are like the Census Bureau's figures on population increases or decreases. You can believe the Census Bureau, or you can take the Chamber of Commerce figures just as you prefer, or you can make your own estimates.

So it is with the oil-producing states. We are not required nor are we under agreement to stick to or abide by the Bureau of Mines estimates of what is going to be needed.

We make our own estimates guided by all the available information we can get, such as stocks of crude, stocks of products on hand, and nominations of purchasers.

Nominations Required

Each month we require all crude purchasers desirous of buying Texas crude to submit nominations for the next month ahead. These nominations are submitted under oath and are firm for the month ahead and best estimates for the five succeeding months. This gives us a picture of demand for six months ahead. We hold a hearing each month to keep abreast and up to date on demand.

Long experience has shown us that there is naturally some duplication and some trade puff in these nominations. But we check monthly on crude stock accumulation or decrease by districts of Texas crude origins.

If Texas crude increased over a month's period, that generally indicates need for a reduction in production of Texas crude.

On the other hand, if Texas origin crude wherever located declines in storage, that naturally indicates generally an increase to meet demand.

Market demand can never be arrived at by the application of a formula. There are many factors we must consider, nominations being just one of these. We must even consider the weather, and certainly the season. We must consider the displacement of coal by oil and the substitution of gas for oil. The increase in use of gas of 2.9 trillion cubic feet in a period of eight years represents a heat value equivalent to the use of 1,320,000 barrels daily of petroleum.

A striking example is the shift of utilities making electric power, which used 42,000,000 barrels of fuel oil in 1948, which was a 6 per cent decrease under 1947. On the other hand, their use of gas increased 28 per cent. Heat value-wise, the increase in gas use amounted to 18,000,000 barrels of petroleum. The estimation of crude requirements for the nation is one that requires constant broad study and observation. The technique of application of the results of these studies required bold decision and prompt action.

The Present Oil Situation

Since World War II there has been a rapid development of the production of oil in foreign areas at a rate greater than could be absorbed by foreign markets. The resulting surplus has been an important factor in the following changes in the operations of the domestic petroleum industry:

1. Oil Production: Domestic production averaged 5,380,000 barrels daily during the last half of 1949. This was a reduction of 10.3 per cent as compared with the same period in 1948.

2. Producing Capacity: Domestic capacity under sound conservation practices averaged 6,380,000 barrels daily during the last half of 1949. This represents an increase of 6.3 per cent over 1948 productive capacity.

3. "Shut-In" Production: The difference between capacity and actual production shows that the domestic industry was "shut in" by an amount averaging 1,000,000 barrels per day or 17 per cent during the last six months of 1949.

4. Oil Imports: Imports of foreign oil during the last half of 1949 averaged 680,000 barrels. This was an increase of 23.6 per cent over the imports during the same period of 1948.

5. Oil Exports: Exports averaged 290,000 barrels daily during the last half of 1949, a decrease of 23.3 per cent as compared with the previous year.

6. Oil Producers' Income: On January 1, 1950, the U. S. Department of Interior reported that the total income of domestic crude oil producers in 1949 was $507,000,000 less than in 1948.

Decreased oil activity in the United States and reduced income from oil production affect American labor, federal and state tax revenues, the prosperity of hundreds of communities in oil-producing areas, and the income and general welfare of the nation. The experience of the industry proves conclusively that a loss in income means decreased drilling activity and a lessened ability to maintain producing capacity to meet national oil requirements. As this takes place, the nation shifts its dependence for oil supplies from thousands of domestic producers to foreign oil controlled by a few large oil concerns operating on a worldwide basis.

Imported oil denies a market by just that much to our domestic producers. It has seemed that as we reduced, more oil was imported. Happily the importing companies are now reducing their importing schedules. A balance between exports and imports would be desirable.

The last year of 1949 saw a decline of exports of 23 per cent, while imports of petroleum and its products increased 23 per cent.

Here is an opportunity for a demonstration of real business statesmanship on the part of the importing companies. World oil trade should not be a one-way street.

Unless imports are cut appreciably and promptly, there will be a lot of forced federal legislation. ★ ★ ★

PLANS CHANGED FOR SYMPOSIUM

In the October, 1949, issue of the JOURNAL and by letter dated October 25, 1949, to registrants at the San Antonio Meeting, an open invitation was extended for submission of prepared discussions relative to the controversial opinions voiced during the formal Well Spacing Session at that meeting.

Upon receipt of such discussion, the Petroleum Branch had intended to give consideration to publishing a symposium setting forth both sides of the argument.

One discussion was submitted by Jack Tarner of the Phillips Petroleum Co. criticizing Tomlinson's conclusions. The Petroleum Branch has never received a text from Tomlinson on his paper entitled "Lost Reserves" and no discussions have been submitted by any other party setting forth arguments in support of his conclusions.

Due to the fact that the only written material available to the Petroleum Branch for symposium material is all in favor of wide spacing, your Executive Committee, at its meeting in New York on February 15, voted to drop from consideration the possibility of publishing a symposium and consider for publication the past and any future submissions purely on their merits as technical papers. ★ ★ ★

DeGOLYER TO RECEIVE COVETED AWARD

Presentation of the highest award in petroleum geology, the coveted Sidney Powers Memorial Medal of The American Association of Petroleum Geologists, will be made April 25, 1950, to Everette Lee DeGolyer, widely known geologist of the consulting firm of DeGolyer and MacNaughton of Dallas, and past-president of the AIME.

The presentation rite will be a highlight of the Joint Annual Meeting of the AAPG, the Society of Economic Paleontologists and Mineralogists and the Society of Exploration Geophysicists at the Stevens Hotel in Chicago, Illinois.

DeGolyer will receive the award in recognition of distinguished and outstanding contributions to, or achievements in, petroleum geology. ★ ★ ★

Adkins Named Editor of Petroleum Technology

Included in the Petroleum Branch staff changes that have been made in recent weeks was the appointment of Jess E. Adkins of Dallas as editor of the JOURNAL OF PETROLEUM TECHNOLOGY. In addition he will function as assistant executive secretary of the Branch.

Adkins is a native of El Paso, Texas. During the early part of the war he was affiliated with North American Aviation in Inglewood, California, engaged in production control work. After serving with the Naval Air Corps for three years during the war, he entered Southern Methodist University in 1946. He received the Bachelor of Business Administration degree in August, 1948, and a B.S. in journalism in January, 1949. He joined the Dallas Times Herald as a reporter in December, 1947, while still in S.M.U., and continued there until his present appointment. He helped to establish the S.M.U. Advertising League and was its second president.

The Adkins family consists of Mrs. Adkins, formerly Roberta Gallagher of Los Angeles, and Michael, age 7. Adkins will participate in all activities of the Branch, and will visit the membership as his duties permit.

Another recent addition to the staff was Miss Marjorie Ann White, who came on February 22 to replace Mrs. Peggy Hardy, who resigned as secretary. Miss White is a native of Dallas and a graduate of S.M.U. in business administration in 1944. ★ ★ ★

February 6, 1950

TO THE EXECUTIVE COMMITTEE:

Subject: Treasurer's Report for Year Ending January 31, 1950

Gentlemen:

As shown by the statement at right, the assets under Branch control amounted to $16,543.31 at the end of the period. Cash assets increased from $10,209.44 to $14,161.73 during the period; this increase being attributable to conversion of reprinted Transactions volumes into cash.

Fall Meetings in 1949 were profitable to the extent of $3,493.03, despite the increased cost of conducting these meetings, but this gain was offset by increased expense on other meetings and upon activities that had not previously been financed by Branch Funds, principally the production of the 1949 Branch Directory.

The Funds were audited on February 3, 1950 by an Auditing Committee under E. R. Brownscombe. The report of this Committee is on file, attesting to the completeness and accuracy of the records involved, and to the adequacy of the accounting system employed.

Respectfully submitted,

Chas. B. Carpenter

Branch Treasurer

STATEMENT OF INCOME AND EXPENSE

SPECIAL PROJECTS FUND
PETROLEUM BRANCH, AIME

From February 1, 1949 through January 31, 1950

History — The Special Projects Fund was created in 1946 to enable the Branch to finance the activities necessary to expansion and improvement of the AIME that were not practically or customarily provided for in the budgeting of the Institute's central funds. Principal sources of revenue have been exhibit booths and registration fees at Branch meetings.

EXPENSE		
Fall Meetings		
San Antonio Exhibit Booths	$1,088.98	
Los Angeles Exhibit Booths	760.57	
Space and Equipment, rentals and services, S. A.	1,281.93	
Space and Equipment, rentals and services, L. A.	845.89	
Preprints, S. A. and L. A.	1,321.83	
Sub-Total		5,299.20
Annual Meeting, 1949		
Staff Travel	367.90	
Preprints	119.35	
Transcript	84.80	
Various	278.31	
Sub-Total		850.36
Other Meetings		281.10
Assistance to Local Sections		
Kansas Section	100.00	
Texas Tech Student Chap.	75.00	
Pacific Pet. Chapter	570.53	
Sub-Total		745.53
Production and Distribution, Branch Directory		2,093.02
Membership Campaign		266.45
General printing, post., misc.		526.83
Purchase of Equipment		458.40
Total Expense		10,520.89
Add cash on hand and in bank as of Jan. 31, 1950, per audit		13,961.73
TOTAL		$24,482.62

INCOME		
From Fall Meetings		
Exhibit Booths, San Antonio	$3,060.00	
Exhibit Booths, Los Angeles	1,882.50	
Registration fees, S. A.	2,107.00	
Registration fees, L. A.	742.50	
From AIME, N. Y., support of meetings	1,000.00	
Sub-Total		8,792.00
From Other Sources		
Anonymous Contribution	1,500.00	
Miscellaneous	22.00	
Sub-Total		1,522.00
Transfer of Publications Fund		5,661.74
Total Income		15,975.74
Add cash in bank and on hand as of Jan. 31, 1949, per audit		8,506.88
TOTAL		$24,482.62

TRUE VALUE OF FUND AT JANUARY 31, 1950	
Cash on hand and in bank	$14,161.73
Accounts receivable, reprinted transactions sales	660.75
Due from AIME, New York	60.00
Value of reprinted transactions	146.50
Equipment on hand (pur. price)	1,514.33
VALUE OF FUND	$16,543.31

NEW ORLEANS IS SITE FOR MID-CONTINENT FALL MEETING

Make Your Hotel Reservations Early

Use Form Inserted Between This and Opposite Page

The Fall Meeting of the Petroleum Branch which is held annually in the Mid-Continent area is slated to be held this year in New Orleans on Wednesday, Thursday and Friday, October 4-6.

Hosts to the meeting will be members of the Delta Section located in New Orleans, of which Fred E. Simmons Jr. of Louisiana Land and Exploration Co. is chairman. Headquarters for the meeting will be in the Roosevelt Hotel, and the technical sessions will be held there. Social activities are as yet in the tentative stage, but they will include the annual cocktail party, banquet and dinner dance, and one or more functions for the ladies. It is expected also that a general luncheon will be held, as well as one mixed function designed to take advantage of some of the entertainment features offered by New Orleans.

Attendance at the meeting is expected to be about 1000 engineers with 200 to 300 ladies. The New Orleans hotels have set aside a block of rooms for the meeting, but it is anticipated that more rooms will be needed than have been reserved. They will grant more rooms when the first block is reserved, thereby demonstrating the need for more. Therefore, it is urgent that you make your hotel reservation early.

Make your reservation by using the form inserted between this and the next page. List the hotels of your choice, as they are shown at the bottom, and send the completed form to H. E. Lowery, 519 Whitney Building, New Orleans 12, La. He will forward your request to the hotel, and the hotel will confirm directly to you.

It is expected that the technical program will be of the same quality as that offered last year at San Antonio. Plans are being made to hold two sessions simultaneously during the three days of the meeting. The Production Technology Committee, under the chairmanship of Morris Muskat of Gulf Research and Development Co. in charge of the program. Vice-chairmen now working with Muskat are Lincoln Elkins of Sohio Petroleum Co. and R. L. Parsons of California Research Corp.

In addition to this meeting in New Orleans, the Petroleum Branch will also hold its annual West Coast Meeting in Los Angeles sometime during the last two weeks of October. This meeting will be outlined in an early issue of the JOURNAL. ★ ★ ★

The picture at top shows the famous Canal Street in New Orleans to where it dead ends on the banks of the Mississippi. To the left is the French Quarter, preserved in its antiquity. To the right is the business district which, along with its harbor facilities, makes New Orleans a key city of the world.

ATTAINMENT OF CONNATE WATER IN LONG CORES BY DYNAMIC DISPLACEMENT

ROBERT L. SLOBOD, MEMBER AIME, THE ATLANTIC REFINING CO., DALLAS

ABSTRACT

In much of the work reported in the literature on long cores, true connate water values probably have not been obtained because of insufficient flow of oil to attain equilibrium. A satisfactory method for establishing connate water in long cores has been developed in which oil flow is maintained until *no* additional water is displaced.

INTRODUCTION

Long cores have been used by severals investigators in an effort to evaluate the efficiency of oil recovery for various producing schemes. The effects of many variables such as rate of displacement, pressure drop, volume of displacing medium, gas-oil ratio, interfacial tension, and others have been investigated, and the merits of gas drive have been compared with water drive. In the older experiments no connate water was used, but in the more recent studies the philosophy of the experiment calls for a core containing oil and connate water (irreducible water) as the starting point of the experiment. The method generally used to establish this condition in long cores involves dynamic[1] displacement wherein one or more phases are forced through the core, flow being maintained at a constant rate or at a constant pressure until a steady state is reached wherein there is no change of saturation with time. It is one purpose of this paper to point out that in much of the work reported in the literature true connate water values probably have not been obtained. The reason for this failure is pointed out, and a method for obtaining more reliable connate water values on long cores is presented. It is impossible at this time to completely evaluate the effect on the conclusions in the earlier papers resulting from the failure to obtain true connate water in the long cores, but some data are presented which indicate that serious errors may be present in many cases.

MATERIALS AND APPARATUS

Cores cut from outcrop sandstones (Strawn, Torpedo, and Elgin sandstones) with permeabilities of the order of 300 md were used. The major experiments were made with a core 18-in. long and 2-in. in diameter. Cores of the same diameter but only 12-in. long were used in a few tests, and in some work a core 1-in. in diameter and 11-in. long was used. These materials were all somewhat bentonitic. To reduce the effect of such constituents, one of the cores (Torpedo No. 10) on which the most work was performed was acid extracted at the start of the experiment.

Brine containing 50,000 ppm chloride and naphtha (Stoddard's Solvent) were used as the water and oil phases, respectively.

The core was mounted in a rubber sleeve which forms the inner lining of a brass cylinder. In this arrangement[2] the rubber sleeve is forced against the core by applying pressure to water in the annular space between the rubber sleeve and the brass cylinder wall. The core is therefore sealed in rubber so that all fluids introduced at the input end of the core flow through the core. With this equipment the core may be easily removed for inspection and analysis. Also, other cores may be introduced for study with no extra time for preparation such as is required when plastic mounting is used.

When pressure or conductivity measurements are desired at intermediate points along the length of the core, the brass cylinder comprising the outer jacket of the core holder is cut into sections of the desired length. Each section is then made up as an individual unit with its own rubber sleeve (see Fig. 1). The individual units are then butted up against a ring of plastic or

[1] References are given at end of paper.

Manuscript received at office of Petroleum Branch August 18, 1949. Presented at Branch Fall Meeting, San Antonio, Texas, October 5-7, 1949.

other insulating material which carries an electrical contact for resistivity measurements and an opening which can be used for the measurements of fluid pressures. The individual units are forced tightly against the plastic ring separators and held in place with several tie rods. Inlet and outlet end butts of the same diameter as the core and several inches in length are provided to control the introduction and withdrawal of fluids and to complete the arrangement for sealing the core within the rubber sleeve. Fluid flow is maintained either by applying pressure to the liquid confined in a reservoir or by the use of a gear pump. The latter is preferable where continuous flow at a moderate rate over a long time interval is desired since a small volume of liquid can be readily recirculated using filters to prevent plugging of the core.

EXPERIMENTAL

The oven-dried core is weighed and is then completely saturated with brine by evacuating the dry core in an appropriate chamber at a total pressure of less than 1 mm of Hg for several hours. Previously evacuated brine is then added to cover the core and time allowed for the brine to saturate the core. The saturated core is weighed and then placed in the core holder where it is driven down to connate water by flowing naphtha through the core until no more water is produced. Small amounts of water discharged from the core are measured accurately by means of inserting the outlet tube from the core into a small graduated cylinder, allowing the water to settle to the bottom of the graduate and the oil to overflow and return to the reservoir. This procedure insures accurate measurements of the cumulative water production over a long period of time. The total volume of oil forced through the core is calculated from periodic measurements of the flow rate. The displacing oil phase is completely saturated with water to avoid dissolving water from the core in the flowing oil. Saturation changes are followed both by resistivity measurements and material balance. The displacing oil phase is carefully filtered to avoid plugging of the core. The change in the residual water content of the core with time is followed by plotting the water content of the core against the log of time. Compressing of the time scale in the plot is necessary to show the continuous but slow displacement of water by oil. The use of a linear time scale leads to the erroneous conclusion that equilibrium is essentially obtained after relatively few pore volumes have passed through the core.

RESULTS

Whenever oil is used to displace water from a core, almost all of the displaceable water *appears* to be recovered ahead of the oil interface. After the oil phase breaks through, a high oil-water ratio is observed which reaches such a large value after several pore volumes that it is common practice to assume that only an insignificant amount of displaceable water remains. Consequently, the water saturation of the core, after perhaps as few as 3 pore volumes of oil have passed through the core, is assumed to be a reliable measure of the connate (irreducible) water. That this procedure is erroneous and can result in serious error is shown by the data in Table I and Fig. 2.

From these data on the water saturation of an acid extracted Torpedo sandstone outcrop core (Table I) it is obvious that not 3 pore volumes but more nearly 3000 pore volumes are necessary to reduce the water saturation to a point where water no longer flows. The water content of the core at this point represents the true connate water value (irreducible water value). In this particular study water was observed to be displaced from the core for 37 days, during which time 2452 pore volumes of oil were forced through the 18-in. core under a pressure head of 20 psi (equivalent to 13.3 psi/ft). For the subsequent 5 days 448 additional pore volumes of oil were driven through the core with no additional displacement of water. Consequently, the experiment was concluded after 42 days with a connate water of 15.0 per cent obtained and with oil-water ratios exceeding 20,-

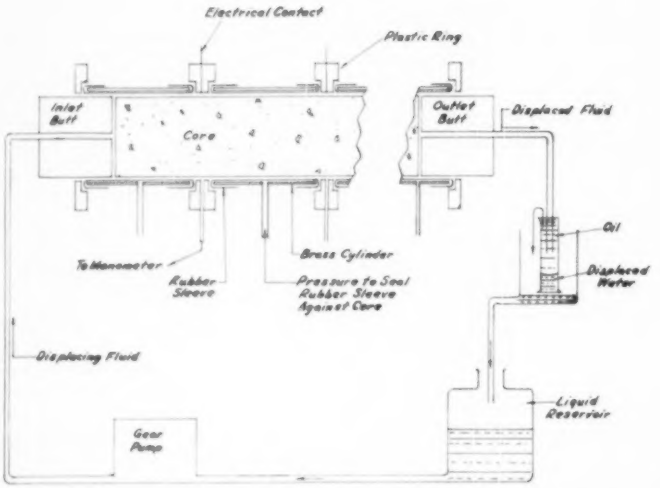

FIG. 1 — SCHEMATIC DIAGRAM OF APPARATUS FOR OBTAINING CONNATE WATER IN LONG CORES.

000,000 observed in the latter stages of the oil drive.

Additional confirmation of the correctness of the connate water value in the vicinity of 15 per cent was provided by a capillary pressure connate water determination on a portion of the same core material which yielded a value of 18 per cent for the "irreducible water."

Similar results have been observed on other cores, the pertinent data being shown in Table II. All of the cores used were cut parallel to the bedding plane of the outcrop sandstone indicated. The residual water content remaining in the various cores after a stated number of pore volumes of oil had been forced through the core, originally saturated 100 per cent with brine, are also given in this table. From these data it is obvious that in all cases relatively high interstitial water values were observed after the use of only several volumes of displacing oil. Increasing the number of pore volumes through the core resulted in lower water values. In Table II the data on core No. 6, a Torpedo outcrop core which was not acid extracted, show that the water saturation was reduced to 34 per cent with 6 pore volumes of oil, 23.5 per cent with 395 pore volumes of oil, and finally 22.2 per cent with 1,165 pore volumes. The experiment was terminated at this point after a flow of 39 days because of apparatus failure. It is assumed that more water would have been produced with continued oil flow until the residual water content was reduced to approximately 17 per cent, in agreement with that observed in capillary pressure measurements on a representative core specimen. The above data confirm the previously discussed results obtained on Torpedo core No. 10 (Table I). A portion of these earlier data on core No. 10 is also included in Table II.

DISCUSSION

In long core experiments it is common practice to assume that connate water has been established using oil as the displacing medium after several pore volumes of oil have passed through the core.[3] This criterion has been accepted because most of the water appears to be displaced ahead of the water-oil interface, and very little additional water is observed in the effluent as the flow of displacing oil is continued. This conclusion is erroneous since a considerable amount of water in excess of connate water may remain in the core, but because relative permeability to water is extremely low, an almost inappreciable flow of water is observed. From the results presented in the preceding section it is obvious that this very small flow rate can bring about a significant change in the water saturation if the flow of the displacing oil phase is continued for a sufficient time. Thus, in the experiment cited the connate water value was reduced from 32 per cent to 15 per cent over a period of approximately 40 days as a result of flowing about 2300 additional pore volumes of oil which displaced an additional 37 cc of water from the core.

These results are obviously of importance in evaluating the use of the dynamic method of establishing connate water. Previously the method was not considered reliable by some investigators because of the high connate water value observed. End effects and other extraneous factors were offered as a partial explanation for the observed high values of water saturation. Now it appears that these results were in error because of failure to drive the core for a sufficient time to reach true equilibrium. The long times (many pore volumes) required to bring a long core to equilibrium are obviously not practical for routine determinations, but the possibility of using the dynamic method for producing connate water in small core plugs offers interesting practical possibilities since much shorter displacing times are required. It is important to note that the use of higher pressure gradients in the long core studies will undoubtedly shorten the time required for establishing irreducible water saturation.

Many variables such as rate of water flooding, pressure gradient, interfacial tension between liquids used, nature of the porous system, temperature, viscosity, and others should be considered in evaluating oil recoveries by water flooding, but the results of the present study are interpreted as indicating that time may be the single most important variable in laboratory studies. Failure to operate for a time interval sufficient for the system to reach equilibrium will undoubtedly result in obtaining meaningless data. Attempts to interpret such data with reference to the part played by the variable in question may result in unfortunate interpretations.

The relation between the pressure used in driving a water saturated core with oil and the connate water value obtained is important. In such flow experiments pressure differences between the phases are generated which desaturate the core in much the same manner as in the capillary pressure method where the core is mounted in a semi-

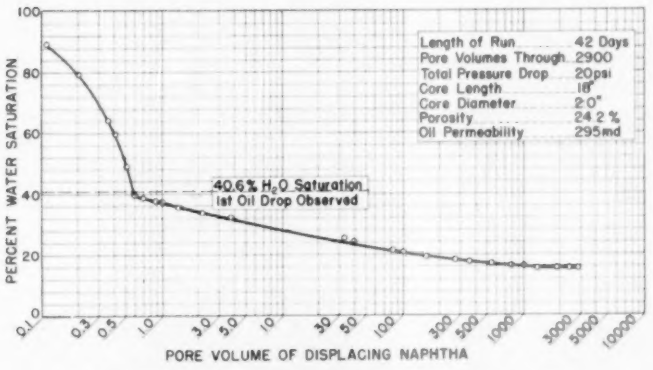

FIG. 2 — INTERSTITIAL WATER SATURATION IN LONG CORE AS A FUNCTION OF PORE VOLUMES OF DISPLACING NAPHTHA.

permeable disc. Some data have been obtained which indicate that if a very small pressure is applied to the flowing oil phase, only a portion of the displaceable water is removed as predicted by the data from capillary pressure studies. Consequently, in long core experiments a pressure gradient somewhat in excess of the pressure required to desaturate the core to connate water in a capillary pressure apparatus should be used. To minimize end effects high pressure gradients should be used and an end butt of similar core material on the output end of the core may be introduced. High pressure gradients may also lead to a more rapid establishment of connate water.

EFFECT OF ERRONEOUS CONNATE WATER VALUES ON RESIDUAL OIL DETERMINATIONS

The effect of erroneously high connate water values in cores used to evaluate the efficiency of various means of production on the per cent of oil recovered is difficult to estimate at this time. It is likely, however, that all of the information in the literature on recovery of oil by flooding which is based on cores with erroneous connate water values is unreliable. Furthermore, these data cannot be simply corrected at present, for there are no accepted generalizations which relate the amount of recoverable oil with the amount of in place oil or the effect of connate water on residual oil. In this connection it is interesting to note that the residual oil for the Torpedo sandstone discussed above was found to be 18 per cent of the pore space for the core containing 15 per cent connate water and 85 per cent oil (see Table III) when driven by water until no more oil was recoverable (water/oil ratio greater than 100,000:1), while the same core with an initial water saturation of 33 per cent (67 per cent oil) was observed to have a residual oil saturation of 30 per cent (when driven until the water-oil ratio reached a value of 600:1). The recoverable oil in the former case amounts to 79 per cent of the in place oil, while only 55 per cent of the in place oil was recoverable in the latter case with the erroneously high connate water value. These differences are of obvious importance and demonstrate the magnitude of the error possible in interpreting experimental data obtained from long cores with improper connate water saturations.

CONCLUSIONS

The establishment of connate water (irreducible water) in long cores is difficult. The passage of only a few pore volumes of displacing oil through the core does not reduce the water saturation to the irreducible value. On the contrary, apparently several thousand pore volumes are necessary. The effect of rate on the time required to obtain connate water may be important, but has not yet been established. Prelimi-

Table I

Effect of Volume of Displacing Oil on Residual Water in Long Cores

No. of Pore Volumes of Displacing Oil	Water Content of Core % of Pore Space	Oil/Water Ratio
0.0	100	—
0.6	40	0*
1.0	37	28/1
3.0	32	106/1
10	28	—
30	24	415/1
100	20	4,650/1
309	18	8,300/1
1000	16	200,000/1
2300	15.03	1,300,000/1
2482	15.00	>10,000,000/1
2900	15.00	>>20,000,000/1

Core Description: Torpedo Sandstone—Oklahoma Outcrop Acid Extracted
Core #10
Porosity 222.7 cc (24.2%)
Oil Permeability = 295 md
Length = 18" Diameter = 2"
ΔP = 20 psi = 13.3 psi/ft

*First drop of oil produced at output end of core.

Table II

Displacement of Water by Oil in Long Cores

Type of Sandstone Used	Core No.	No. of Pore Volumes of Flooding Oil	Time of Flood	ΔP/ft.	Water Saturation
Torpedo	8	2.5	1050 min		44 %
Torpedo	8	7.5	1400 "	10	39
Elgin	7	1.6	500 "		44
Elgin	7	6.5	1360 "	20	33
Elgin	5	1.5	63 "	13.3	46
Elgin	5	4.5	1175 "	20	35
Torpedo	6	0.67	75 "	16.6	45
Torpedo	6	1.0	90 "	20	45
Torpedo	6	6.0	300 "	13.3	34
Torpedo	6	395	215 hr	13.3	23.5
Torpedo	6	1000	540 "	13.3	22
Torpedo (acid extracted)	10	0.6	23 min	13.3	40
Torpedo	10	1.0	40 "	13.3	37
Torpedo	10	6.0	310 "	13.3	30
Torpedo	10	1000	390 hr	13.3	16
Strawn	5	2.5	103 min	25	58
Strawn	5	3.5	165 "	32	56
Strawn	5	20	200 "	25	51

CORE DESCRIPTION

Torpedo # 8	Length = 12"	Dia. = 2"	Pore Space = 175 cc	Porosity = 28.4%
Torpedo # 6	" = 18"	" = 2"	" = 220 cc	" = 23.9
Torpedo #10	" = 18"	" = 2"	" = 223 cc	" = 24.2
Elgin # 5	" = 18"	" = 2"	" = 203 cc	" = 22.0
Elgin # 7	" = 12"	" = 2"	" = 163 cc	" = 26.4
Strawn # 5	" = 11"	" = 1"	" = 122 cc	" = 19.1

Permeability of above cores 200—600 md

nary data indicate that flooding experiments to determine recoverable oil using long cores with incorrect connate water values are not reliable.

Table III

Effect of Original Saturation on Oil Recovery

Run No.	Original Saturation		Content after Water Flood		Water/Oil Ratio at Termination	% of Original Oil Recovered
	Water	Oil	Water	Oil		
A	15%	85%	82%	18%	100,000/1	79%
B	33%	67%	70%	30%	900/1	55%*

*On the basis of run A, only a negligible increase in recovered oil would be expected after reaching a 600/1 water/oil ratio.

ACKNOWLEDGMENTS

The author gratefully acknowledges the cooperation of Miss E. A. Chambers and Raymond R. Hawthorne in carrying out the experimental portion of this study.

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2. Hassler, U. S. Patent No. 2,345,935, April 4, 1944.
3. J. N. Breston and R. V. Hughes, *Jnl. of Petr. Tech.*, 1, No. 4, 100 1949.
4. *Producers Monthly*, 13, No. 2, 14 (1948). ★ ★ ★

DISCUSSION

By Martin Felsenthal, Production Laboratory, Continental Oil Co.

It is most interesting to note the great number of pore volumes of oil required in the attainment of true irreducible water saturation by dynamic displacement as described in Slobod's note. The displacing fluid used in these tests was naphtha. It is believed that less pore volumes of displacing fluid would have been required had a more viscous displacing fluid been chosen. This belief is based on observations which were made during a recent series of tests on the effect of viscosities on water flooding. Preceding each water flood of this series, an attempt was made to reach a uniform initial water saturation in a long core by dynamic displacement of brine by oil. It was found that the water saturations at oil break-through decreased with increasing oil viscosities. Thus, at oil breakthrough, only 0.65 pore volumes of a 30 centipoise oil (a 91-9 per cent mixture of mineral oil and naphtha) was able to effect a lower water saturation by dynamic displacement than did 54 pore volumes of a 0.44 centipoise oil (naphtha). The flow rate at a given pressure drop immediately following oil break-through was not as unfavorable for the more viscous oil as might have been supposed from a consideration of the viscosity ratio alone, since effective permeability to oil was considerably higher for the more viscous oil due to the higher oil saturation. In order to speed up the process of reaching irreducible water saturation by dynamic displacement, it may perhaps be feasible to remove the bulk of the displaceable water with about one pore volume of a high viscosity oil (e.g., mineral oil) and then complete the process with the aid of naphtha.

Results cited in Slobod's note for Runs No. A and B tend to refute the general accepted theory that residual oil saturation attainable by water flooding is independent of initial oil saturation provided the initial oil saturation is above a certain limiting value. It would be interesting to obtain a few more data on the two water floods, especially the oil saturation at the time of water break-through.

Author's Reply to Martin Felsenthal

The comments of Felsenthal on the use of high viscosity oils to displace water from porous systems are pertinent. We have observed similar beneficial action. The displacing efficiency obviously increases with increase in the viscosity ratio expressed as $\frac{\text{viscosity of oil}}{\text{viscosity of water}}$. At the highest ratio in our experimental work to date (approximately 100), however, displaceable water was still present in the core after flooding with 10 pore volumes. In a typical experiment on a small core plug (1-in. long) 20 per cent of the water remained in the core at oil breakthrough. Nine additional pore volumes of this high viscosity oil reduced the water saturation to 15 per cent of the pore space. (Irreducible water in this plug is 10 per cent.) In the same core, using a low viscosity oil (viscosity oil/viscosity water=1.4), the water saturation at oil breakthrough was approximately 35 per cent of the pore space, and, after 10 pore volumes of displacing oil had flowed through the core, the water saturation was 23 per cent. Thus, 10 pore volumes of low viscosity oil (viscosity ratio 1.4) are not as effective as one pore volume of high viscosity oil (viscosity ratio 100), but even with the high ratio oil (100) apparently a considerable number of pore volumes will be required to establish "irreducible water." ★

1950 Annual One Of The

Most of the 3,000 people who attended the Annual Meeting of the Institute, held in New York February 13-16, agreed that it was one of the best and one of the most successful ever held. All of the technical programs were of a high caliber, the entertainment features were enjoyable, and the total attendance one of the largest on record. The Statler Hotel in New York was headquarters for the meeting.

A highlight of the meeting, which started it off on a note of enjoyment and success, was the Welcoming Luncheon on Monday, February 13, at which Dwight D. Eisenhower, president of Columbia University, was the speaker. Tickets for the event were sold out by mid-morning on Monday, and the large crowd of both men and women were delighted to receive favors presented by The M. A. Hanna Co. in the form of cigarette lighters with the AIME insignia imprinted on them.

In speaking to a very attentive audience, Eisenhower stated his belief that the danger to our country now is greater from within than it is from without. He stated that he does not feel that if we should move slightly in one direction we will "fall into an abyss"; and that if we move several steps in the opposite direction we will be saved completely. He added that we have reached a peculiar position in our national government, however, because of the necessity for our vast war and economic expenditures, and that we should move forward cautiously. His address was well received.

Another highly enjoyable feature of the meeting was the Annual Banquet on Wednesday evening in the ball room of the Statler. Retiring President Lewis E. Young presided, introducing a large group of distinguished guests, and handing the custody of the AIME for the ensuing year to incoming President Donald H. McLaughlin. The American Smelting and Refining Co. presented favors of silver Mexican coins encased in solid blocks of clear plastic, 1 in. by 2½ in. by 3 in., to form paper weights. The coins are descendants from "Pieces of Eight," in that they contain one Troy ounce of silver, and their value as money depends upon the price of silver at any given time.

Petroleum Branch Program Good

A program that was somewhat limited in scope, but high in quality was well attended and received by Petroleum Branch members attending the meeting, of which there were about 200.

Ernest O. Thompson, Railroad Commission of Texas, authored a paper presented before a petroleum economics session in which he said that proration of crude production to market demand, as practiced in Texas, has built up a healthy and expanding oil industry, provided reserves, and given each well a fair share of production. Thompson also stated that if Congress reduces the depletion allowance, oil exploration would be proportionally cut down by the operators, even to the point of stopping discoveries.

Meeting Was Best Ever Held

Jerry A. Cogan, manager of the Economics Department of Standard Oil Co. of N. J., outlined variables that are important in petroleum supply nd demand projections. Chief among these is weather, and it has become so important that studies have been made within the oil industry of the possibility of long-term weather trends or cycles. Other factors are: the general pattern of business; developments in the fields of competitive energy sources, and human vagaries or psychological factors.

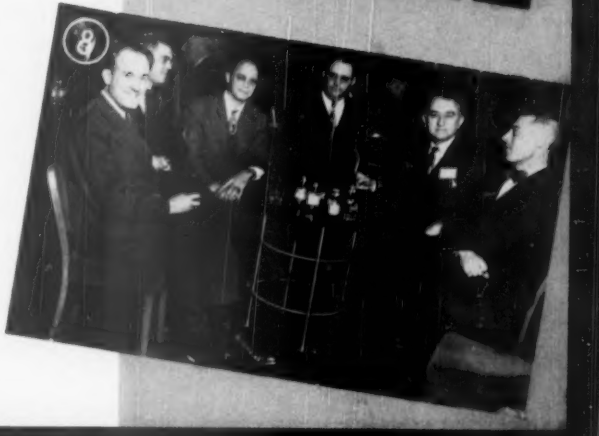
A new logging method, trademarked MicroLog, was described by H. G. Doll of Schlumberger Well Surveying Corp. in a technical paper. American oil shale on developments, primarily in the U. S. Bureau of Mines, were described by J. B. Mull of the Bureau. Robert A. Howard of Oklahoma University presented a paper on the relative productivity of perforated casing co-authored by Marsh S. Watson Jr.

Reports on domestic production during 1949 were presented in the Production review session, and a production technology seminar was held, (see pictures at left and right).

In the Pictures

1 — Four key participants in the welcoming luncheon on Monday are L to R: Fred V. Seibert, president of the Canadian Institute of Mining and Metallurgy, who spoke briefly on behalf of his organization; Cornelius F. Kelley, board chairman of Anaconda Copper Co., who introduced Eisenhower; Dwight D. Eisenhower, luncheon speaker, and L. E. Young, AIME past-president who presided.
2 — An interesting feature of the Petroleum Branch program was a seminar on production technology. R. V. French, left, of Sohio, presented the management viewpoint; C. V. Millikan of Amerada presented the engineering viewpoint, and Morris Muskat, right, of Gulf Research, presented the research viewpoint.
3 — Henry Waszkowski, second from left, chairman of the Oklahoma City Section, makes a point in a discussion with a group at one of the sessions.
4 — A production review session, which presented the highlights of world-wide production developments during 1949 was well received by those attending. Shown presiding at the session are, L to R, D. V. Carter of Magnolia, chairman of the Petroleum Branch Production Review Committee for 1950; E. W. Berlin of Standard Vacuum, vice-chairman for foreign; and R. B. Gilmore, DeGolyer & MacNaughton, vice-chairman for domestic.

5, 6, 7, 8 — Members and their guests enjoy a social hour before the Petroleum Branch Banquet, on February 14. Lloyd E. Elkins, retiring Branch chairman, presided at the Banquet, highlighted by the presentation of a watch to William H. Strang in appreciation of his services to the Branch, and by an address by Tom Orr. Orr is executive secretary of the Kansas Independent Oil and Gas Association, and he spoke on "Whose Business is This?", giving an analysis of the Hoover Commission report, and explaining why it is important to everybody.



KANSAS SECTION ACTIVITIES . . .

Planning, Development And Operation Of Water-Flood Project Discussed

By L. G. Chombart

Carl Pate of the Oil Field Research Laboratories in Chanute, Kan., discusses major phases of water-flood projects at the Kansas Section's recent meeting.

The three major phases of a water-flood project and the many factors which must be taken into consideration in each phase were discussed by Carl Pate of the Oil Field Research Laboratories in Chanute, Kan., at the Kansas Section's first meeting of the year, January 31, in Eureka, Kan.

The phases analyzed by Pate were planning, development and operation. He pointed out that in the planning stage, some of the factors which should be considered are the type of land, the previous productive history of the sand to be repressured (a sand with a good past record is likely to respond well to water flooding), and the gravity and viscosity of the oil (if very viscous leave it alone.) Other factors are the depth and thickness of the sand, whether the property has already been repressured by air and the availability of suitable water supplies.

In connection with the last phase, Pate advised the use of salt water, more easily taken by sand, in preference to fresh water but the formation of sulphide iron plugging the sand should be watched when using Arbuckle water.

Important features of the development phase are possible utilization of the old holes, or if not used, their effective plugging; establishment of the pattern of injection wells and producing wells; coring of sand and determination of at least its permeability in at least all injection wells and sometimes in the producing wells. Other features are methods of completion in both types of wells; shooting if advisable and if not likely to result in shot fractures through which much of the water could bypass the sand; construction of suitable facilities to treat water (tower, pits, etc.); drilling of water supply well and completion by setting casing through, cementing effectively and perforating.

In the operating phase, the importance of an efficient operator who keeps close and regular control of the various parts of the system is paramount, Pate said. As a rule, the most efficient operation is that which insures the most uniform drive possible, at a pressure lower than the break-through pressure. The latter should be deter-

Continued on Page 42

The three Kansas Section members in the picture at left indulge in a post meeting discussion. They are, left to right, Rex Staplin, L. G. Chombart and M. C. Harrell. In the center picture, J. A. Cummin, Clift Blackburn and John Dougherty find the chairs at the Eureka Country Club made to order. In the panel at left, V. O. Austin, left, leans comfortably in a doorway as Paul De Lozier drives home a point.

SOUTH PLAINS SUB-SECTION . . .

Subsurface Hydraulic Pump Explained To West Texans

By Robert R. Shaffer

The relatively new Kobe hydraulic pumping system and its uses was explained in detail to members of the South Plains Sub-Section by Harold Ihrig, manager of Technical Service for Kobe, Inc., of Oklahoma City, at the group's February meeting in Brownfield, Texas.

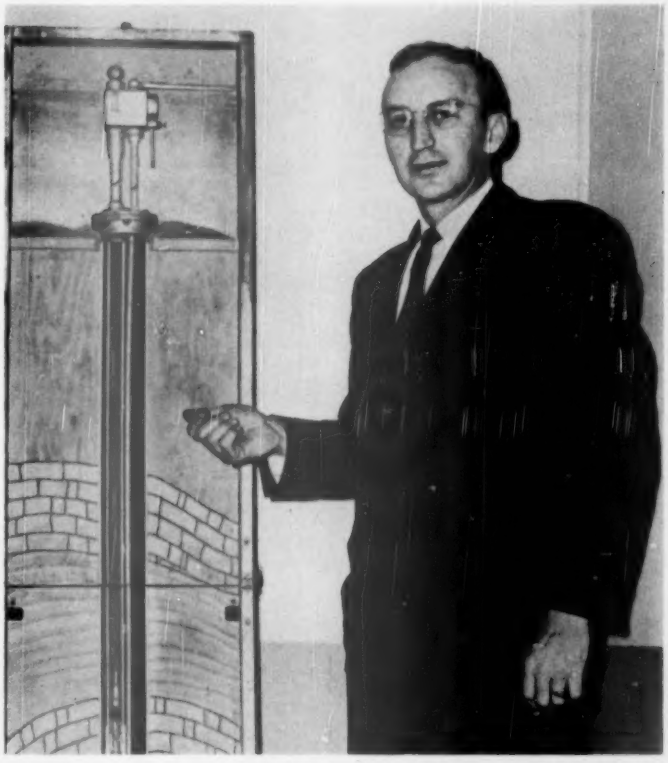
More than 70 members and guests of the Section heard Ihrig talk on the pumping system. The talk was of particular interest to most production men and engineers in the area because the system is relatively new and not so widely understood as the conventional beam-type pumping system.

Ihrig said the Kobe system was designed and first installed in California in 1932. The designer, in studying subsurface pumping equipment, had investigated all means of transmitting power from the ground surface to the lower portions of a well bore. His investigations led to the development of a hydraulically operated subsurface unit known as the Kobe Pump.

The subsurface product unit consists of two principal parts, an upper or engine assembly and a lower or production assembly. The engine assembly operates in much the same manner as does a one-cylinder reciprocating type steam engine while the production end operates like a reciprocating steam pump.

Power oil is pumped from the surface to the engine assembly through a string of one inch high pressure tubing which is run inside the regular tubing string.

The operation of a fluid actuated engine valve allows high pressure power oil to be applied to one end of a piston. At the same time, exhausted power oil on the other side of the piston is discharged from the pump into the annular space between the one-inch and regular tubing strings.



Harold Ihrig, manager of Technical Service for Kobe, Inc., of Oklahoma City, explains action of the company-developed hydraulic pump to members of the South Plains Sub-Section at its February meeting.

The exhausted power oil returns to the surface along with the well fluid that has been pumped into the same annulus by the production assembly of the unit. Since the engine piston and the production plunger are both mounted on the same shaft and are separated by a distance of less than three feet, the length of stroke of each is identical.

The piston and plunger displacement are also identical if the diameter of each is the same.

The Kobe "free" pump is a modification of the conventional Kobe hydraulic pump, Ihrig said. In the "free" system, the one-inch tubing is clamped on the outside of the regular tubing string and is connected to a specially designed seating nipple. The subsur-

Continued on Page 42

PACIFIC JUNIOR GROUP . . .

More Viscosity Research Needed For Future Deep Hole Drilling

By Harold E. Nissen

Drilling fluid viscosities must come in for more intensive study if deep holes are to be drilled successfully in the next five to ten years in the opinion of W. T. Cardwell, Jr., who is engaged in drilling and production engineering research for the California Research Corp.

Speaking to the Junior Section of the Pacific Petroleum Chapter of AIME last month, Cardwell delved into the complex actions of drilling fluid and pointed to the problems which the industry is experiencing as a result. Eighty-five members of the section were in attendance.

Cardwell said that drilling fluid viscosities are not instrumental quantities but rather a property of the elements of the fluid of which the industry is dealing. A fluid is distinguished from a solid in that it can readily be sheared. There is some resistance to shearing in all fluids and this force is called viscosity, he explained. Viscosity is defined as the ratio of shearing stress to shearing rate.

W. T. Cardwell, Jr., drilling and production research engineer for California Research Corp., explains drilling fluid viscosities to members of the Pacific Chapter Junior Section at the February meet.

The California researcher pointed out that a drilling fluid is the most complicated kind of fluid because it has an infinite number of viscosities and does not behave like water and oil which have only one viscosity.

Light shearing stresses have no apparent effect on drilling fluids and this phenomena is known as the gell property of the fluid. The past history is important because it determines the viscosity of a drilling fluid. He added that thixotropy is a rather loose term which is applied to drilling fluids. There are two definitions used which are not identical. One, a fluid is said to be thixotropic if it has a different viscosity under different shearing stresses. Two, a fluid is also said to be

Continued on Page 43

An after dinner informal discussion is participated in by members of the Pacific Junior Group. They are, left to right, R. D. Townsend, Jr., of General Petroleum; W. E. Woodruff, of Technical Service Co.; R. L. Boyes, of Union Oil Co.; and F. H. Hayes, of Bell and Burden Co.

New officers of the Pacific Chapter Junior Section are, left to right, Norman Clark, chairman; Al Marshall, program chairman; Bill Paul, membership; Harold Nissen, secretary; and R. L. Parsons, treasurer. A new chairman was to be elected this month to replace Clark who is being transferred.

EAST TEXAS SECTION ACTIVITIES . . .

The Need For 20,000-Foot Drilling Termed Inevitable In Near Future

By Peter G. Burnett

John M. Payne, division mechanical engineer for Shell Oil Co. in Kilgore, Texas, told members of the East Texas Section at the February meeting that with oil being produced at the present time from below 15,500 ft, it is inevitable that the need for 20,000-ft commercial drilling will develop in the near future.

Payne presented a paper entitled "A Study Group Investigation of Equipment and Techniques for 20,000-ft Drilling" at the East Texas Section's February 14 meeting.

In his introductory remarks, he stated that many equipment limitations already have been reached in drilling the record wells of today. Deep drilling is an exact science for which equipment must be carefully engineered if it is to do a specific job. Although one rig has successfully drilled to more than 20,000 ft, drilling in different localities as well as completing a well at that depth (all within a reasonable amount of time and expense) may offer a large number of problems which have not been solved.

Payne's talk covered the selection and design of all the types of equipment which are necessary in 20,000-ft drilling. Some of the highlights of his talk follow:

The selection of drill pipe and casing is one of the most important considerations involved in the investigation of 20,000-ft drilling. Their sizes and weights must first be determined as a basis for hoisting loads, pump requirements, rotating loads, hole sizes and many other related factors.

Design of casing must allow for extremes. The maximum pressure which might be encountered would equal the weight of the overburden, which is 1 psi per ft or 20,000 psig. The maximum temperature which might be encountered is 500°F which is a gradient of 2.2°F per 100 ft.

Drilling to 20,000 ft with security will require stronger drill pipe than the present API grade E. In the design of prime movers and hoists, the maximum hook loads anticipated are 250 tons for drilling and 400 tons for running casing. However, the drilling load is the key factor as casing loads can be handled by additional lines and slow speeds.

The mud pump has always been the largest consumer of energy in drilling a well. This horsepower requirement, transformed into mud volume and pressure, increases almost directly as the depth for a given size drill pipe in a given size hole. Inasmuch as the primary function of the drilling mud is to remove the cuttings from the hole, the pump size is largely dependent on the size of the cuttings and on the necessary rate to circulate out the drill cuttings.

With increases in depth to 20,000 ft, inaccuracy with the use of drill cuttings will increase considerably over current experience. Errors in depth measurements will also increase and correct perforating will depend more and more on correlated logging methods, such as radioactive markers, gamma ray, neutron logs, casing-collar counters and others. From a mechanical standpoint, electrical logging at extreme depths should not prove difficult.

However, high temperatures affect the resistivity of muds so strongly that much study should be given to the elimination of this difficulty. Indications are that F. M. logging may be used successfully at temperatures up to 350°F.

Present types of cement are not adequate for 20,000-ft completions. Tests show that an average of one hour and 11 minutes in pumpability time may be expected from current types of slow-setting cements in an ordinary temperature gradient well. It is also felt that high pressures seriously accelerate the setting time of cements.

John M. Payne, division mechanical engineer for Shell Oil Co., was speaker at the February meeting of the East Texas Section. He received his B.S. in petroleum engineering from the University of Texas in 1941 and joined Shell in 1944.

Although laboratory results indicate that present cements are inadequate for 20,000-ft drilling, the oil industry has already witnessed the drilling and cementing of one well close to this depth. Results obtained on this well prove that it is possible to secure a casing string at such a depth with the cements now available.

However, it would be unwise to lessen attempts to develop a safer and more suitable product. At present, plastics are limited in use at high temperatures although high temperature plastic probably can be developed. Indications are that floating equipment will have to be made stronger in order to stand increased volumes of circulation and abrasion. The present design of packers is definitely not adequate for depths below 13,000 ft. ★ ★ ★

MID-CONTINENT SECTION . . .

Well Spacing Paper Reread Before Group

By G. M. Stearns

The last regular meeting of the Mid-Continent Section was held in Lorton Hall at Tulsa University on January 9, 1950. F. H. Callaway, petroleum engineer for Stanolind Oil & Gas Co., presented a paper entitled "Critical Analysis of the Effect of Well Density on Recovery Efficiency." This paper was prepared jointly by F. H. Callaway and W. O. Keller of Stanolind, and was originally presented at the fall meeting of the Petroleum Branch in San Antonio. By popular demand, Callaway and Keller were asked to repeat the presentation before the Mid-Continent Section.

An interesting discussion period followed the formal presentation. It was evident from this discussion that many pertinent phases of the broad subject of well density and recovery efficiency are controversial, and that the subject constitutes a real and current problem requiring continuous technical analysis.

Roy H. Smith, vice-president in charge of programs presided at the meeting. Herbert M. Cooley, section chairman, handled projection apparatus.

Annual Joint Meet Set For May 5-6

The date for the second annual joint meeting of the Mid-Continent and Oklahoma Sections, formerly set for April 28, 1950, has been changed to May 5-6.

The two-day meet will be held at Tulsa University in Tulsa, Oklahoma. Participants in the program will be the Mid-Continent Section, Oklahoma City Section, industry representatives, Tulsa University, the University of Oklahoma and Oklahoma A&M College. Site of the meeting will be Lorton Hall at Tulsa University.

On January 24 Ralph W. Warkentin, engineer for Lane-Wells Co., presented a discussion entitled "Comparison of Bullet-Shot Perforating with Cone-Shot Perforating." In this discussion Warkentin compared the two perforating methods from the standpoint of basic design, character of perforations, penetration, fracturing of formation, and other practical aspects. Approximately 60 engineers were in attendance, and an interesting discussion period followed the formal presentation.

At the regular monthly meeting of the Reservoir Engineering study group January 31, a discussion of methods used in appraising oil producing properties was presented to an overflow crowd of approximately 75 engineers.

During the first part of the meeting, J. J. Arps of the British-American Oil Producing Co. explained the stepwise procedure by which oil reserves of an actual oil producing property was evaluated, using actual field data. Kenneth R. Teis, consulting engineer, then explained by steps the procedure for arriving at gross income, operating expenses, present value of future net income and other pertinent economic factors.

Clayton Arnold of the National Bank of Tulsa and W. L. Kendall of the First National Bank, Tulsa, explained the procedure by which a bank would examine the appraisal with regard to the granting of a loan on the property. C. H. Keplinger, engineering consultant, presided as chairman during the discussion period following each phase of the presentation. ★ ★ ★

ILLINOIS BASIN CHAPTER . . .

Recent Developments In Electrical Logging

By Richard W. Love

Charles Doh, Mattoon area manager for Schlumberger, gave a brief review of postwar developments and a detailed analysis of the performance of MicroLogging in the Tri-State area at the recent meeting of the Illinois Basin Chapter.

Doh pointed out that the instrument has shown valuable information in sandstones and limestones and has facilitated the solution of the following problems:

1. Determination of permeable zones, irrespective of fluid content.
2. Obtaining additional detail which may be used for plugging back to hard thin streaks, setting casing as high as possible or below a gas cap, and calculating of potential reserves.
3. Evaluation of pay thickness in critical cases before testing is decided.
4. Precision gun perforating close to water or gas levels.
5. Obtain logs in areas where it had been impossible to obtain satisfactory results due to salty muds.
6. Determine zones of possible caves.

Doh was graduated as a mechanical engineer from the University of Paris in 1933 and after a year in the Signal Corps of the French Army, he joined Schlumberger and was trained in Roumania and Trinidad.

His first real assignment was in Eastern Venezuela where he spent three years. In 1938 he went to East Texas.

The year 1940 marked the beginning of his Illinois career. From Loudon to Mt. Vernon, he went to Mattoon in 1945 as area manager. ★ ★ ★

PERMIAN BASIN CHAPTER . . .

Improved And Effective Well Completions Brought To West Texas By Acidization

By Tom Flewharty

Acidization has brought more improved and effective oil well completions to West Texas, Bill R. Weaver, field engineer for Tide Water Associated Oil Co., pointed out to members of the Permian Basin Chapter at its January meeting in Odessa, Texas.

Leading the discussion were W. M. (Bill) Osborn of the Western Co. in Midland and Jack Moore of Dowell, Inc. The group concluded that acidization of oil wells is advancing at a rapid rate and is developing into a specialty in its own right.

Weaver said that acidizing should accomplish two things: break down the formation and increase the porosity and permeability of the formation near the bore hole. The title of his paper was "Acidization in the Permian Basin." He illustrated the technical lecture with slides and covered the most recent advancements in Permian Basin acidization.

Weaver said that best results from acid treatments are obtained in limestone and dolomite and the poorest are in sand and anhydrite. Most extensively treated zone in West Texas is the San Andres.

Negative results of a treatment is that the acid may form an acid and oil emulsion or place a water block in the formation or dissolve material which may later be reprecipitated when the acid is spent.

W. N. (Bill) Little, section chairman, presided at the meeting which was attended by 140 members from throughout the Basin. Little appointed assistants for two committees and a new member for the organization's board of directors.

D. V. Kitley, district engineer for the Ohio Oil Co. in Midland, was named a board member, replacing Little who is not permitted to serve as an officer and member of the board simultaneously. Other board members are Tom Frick, division operating supervisor for the Atlantic Refining Co., and Jack Moore of Dowell, Inc.

Bruce Ramage, with Bethlehem Steel in Odessa, R. S. Ousterhout, with Dowell, and C. H. Priddy, with Humble Oil and Refining Co., will work with Joe Chastain on the membership committee. C. L. Rabe of Shell Oil Co. in Odessa and Ray Howard of Atlantic will aid Vice-Chairman C. M. LaLonde, of Phillips Petroleum Co., in planning the programs for 1950.

Bill R. Weaver, field engineer for Tide Water Associated Oil Co., presented a paper on acidization at January meeting of Permian Basin Chapter in Odessa, Texas.

Weaver, who delivered the paper on acidization, attended Texas A&M College, the University of Texas, and the University of Oklahoma, obtaining a degree in petroleum engineering. He has worked for the Western Co. and Dowell Incorporated. ★ ★ ★

Officers of the Permian Basin Chapter are, left to right, Joe Chastain of Midland, secretary-treasurer; W. N. Little of Midland, chairman; and C. M. LaLonde of Odessa, vice-chairman. They head the chapter for 1950.

Speaker and discussion leaders at the Chapter's meet were, left to right, Jack Moore, of Dowell, Inc., Bill R. Weaver, of Tide Water, and W. M. (Bill) Osborn, of Western Co. Osborn and Moore led the discussion.

OKLAHOMA CITY SECTION . . .

Maximum Recovery Through Spacing Discussed by Oklahoma Engineers

By H. Robert Sells

The long-standing controversy centering around the question of how closely or how widely oil wells should be spaced to obtain maximum recovery was given both the technical and non-technical approach on February 23, 1950, at the Biltmore Hotel, scene of the monthly Oklahoma City Section meeting.

The technical approach was supplied in major part by the speakers of the evening and the non-technical by members and guests participating in the discussion following the formal presentation. One of the leaders who advanced a number of pertinent questions in this particular discussion is an Oklahoma City attorney.

The group had as their guest speakers W. O. Keller, reservoir engineering supervisor, and F. H. Callaway, petroleum engineer, both of Stanolind Oil and Gas Co., Tulsa, Oklahoma. The two men presented a paper entitled "Critical Analysis of the Effect of Well Density on Recovery Efficiency," which was originally read at the October meeting of the Petroleum Branch of the AIME in San Antonio.

Sixty-five members and guests attending the meeting heard Keller and Callaway give a thorough discussion of the history of the well spacing problem and the various theories that have been advanced since the first article was published on the subject in 1924. This first article was written by W. W. Cutler, Jr., and appeared in the Bureau of Mines Bulletin No. 228. Cutler attempted to analyze the relationship of well spacing versus recovery of crude oil from a reservoir. According to the two Stanolind engineers he was also the first of many who have failed to recognize the essential difference between lease recovery and recovery efficiency.

W. O. Keller, Stanolind Oil and Gas Co., making a point in his critical analysis of well spacing. Seated at the speakers' table are Section Chairman Henry Waszkowski of Magnolia, center, and F. H. Callaway, Stanolind, co-author of the paper being presented by Keller.

In reviewing Cutler's theories, Keller said that he was in error on all points needed to prove his beliefs. One, he failed to recognize that regional migration was the chief reason for the higher recoveries which he observed in more densely drilled tracts. Two, he was wrong in assuming that linear flow principles applied to oil well drainage patterns. And finally, he erred in thinking that reservoir energy not used in flowing oil to the well bore would be saved in the ground to produce additional oil.

After discussing other theories which have been advanced by various writers since 1924, Keller and Callaway proceeded to review the concepts of reservoir mechanics with regard to the well density-recovery relationship. They stated that there is now available a great mass of data of the type required to answer the question of proper well spacing. These records not only show that with very few exceptions, present spacing is adequate, but they also prove that considerably wider spacing could actually have been used in many fields without any appreciable loss in oil recovery, according to the reservoir specialists.

Keller and Callaway concluded their discussion by expressing the opinion that modern reservoir engineering can solve the well spacing problem.

The large gathering of AIME members from the Oklahoma City area actively participated in the discussion session which followed the well spacing speech. In answer to a question of

data clarification, Keller stated that a large portion of the data was secured from West Texas limestone reservoirs. Keller emphasized the point that the type of reservoir was not significant, but that the major point to note is that continuity exist throughout the reservoir in question.

The information was volunteered by one of the engineers present that the results of an infill drilling program conducted by his company in a Deese Sand reservoir gave production from the new infill wells never greater than one barrel per day more than existing wells in the surrounding area. Information was also volunteered that in interference tests conducted in a sand reservoir with average permeability of 15 millidarcies, pressure drops were shown to exist over a distance of one and one-half miles.

Specific questions and summarized answers follow:

Q. Will one well drain the reservoir?

A. This logically follows from the preceeding discussion. One well would drain a continuous reservoir, if properly located, but over a long time interval.

Q. Do rates of withdrawal affect recovery in a depletion type reservoir?

A. No, no effect.

Q. Do changes in relative permeability affect the results?

A. Changes in relative permeability which resulted in the changes in reservoir pressure were taken into account in the calculations. This applies also to viscosity changes of the oil.

Q. Will gravity drainage alter the concept presented?

A. Essentially, no.

Q. Could a stratified reservoir be included in this analysis?

A. Yes, a series of separate reservoirs each continuous within itself will react in accordance with the analysis. It is to be understood, however, that each separate strata will probably vary in residual oil saturation, etc.

Q. If the foregoing analysis applies to the steady state, what of the unsteady state?

A. The complexity of the mathematics involved in unsteady state calculations requires a tremendous amount of time for their solutions. For this reason, unsteady state conditions must be approximated by a series of steady state calculations. In the event unsteady state calculations were used, it is to be expected that lower pressure differentials would result.

Q. What is the ultimate answer to the well spacing problem?

A. The dollar sign.

Local News

Outstanding news flash of the year is credited to Chairman Henry Waszkowski for his report that the directors of the Petroleum Branch of the AIME have accepted the invitation of the Oklahoma City Section to hold the Petroleum Branch Fall Meeting for 1951 in Oklahoma City.

Credit must also be given Chairman Waszkowski for journeying to the Annual Institute Meeting equipped with the statistics, as every good engineer should be. "Statistics" included letters of invitation from Mayor Allen Street and from the Oklahoma City Chamber of Commerce, along with the definite promise of 500 hotel reservations for those attending the 1951 meeting.

The meeting will be held in October, with exact dates to be announced later. To be the hosts for a Petroleum Branch Meeting is a major undertaking on the part of the Section and will require the cooperation of all Section members. You may look toward a request for your services to assist in preparations for this important event. ★ ★ ★

Gulf Coast Section

By J. E. Kastrop

R. W. Johnston of The Texas Co. spoke on the "Fundamentals of Permeability" at the recent meeting of the Gulf Coast Section's Reservoir Engineering Study Group at the Shell Research Laboratory in Houston, Texas.

J. S. Levine, co-chairman of the group, introduced Johnston who developed equations for linear and radial flow of both compressible and noncompressible fluids and discussed the alteration in permeability which may be effected through an interaction of water or brine and clay minerals present in the rock.

The nature of the so-called Klinkerberg slip effect was explained and mention was made of the magnitude of the error involved if it is not taken into account.

The remainder of the presentation was devoted to a discussion of effective and relative permeabilities and the dependence of these quantities on fluid saturation.

The group discussion which followed Johnston's presentation was concerned with such points as end-effects in effective permeability measurements, the cause for water and oil cut-off and the differences between relative permeability curves for sandstones and limestones.

Approximately 50 engineers from Houston and surrounding areas were in attendance. The meeting was held February 9. This group, since its organization last fall, meets on the second Thursday of each month. ★ ★ ★

DELTA SECTION

A group of Delta Section members at the February meeting discuss the various aspects of A. W. Bounds' talk on "The Legal Aspects of the Tidelands."

STUDENT SECTION ACTIVITIES—

University of Oklahoma

By Bob True and Alton B. Slaybaugh

The meeting of the Petroleum Engineering Club at the University of Oklahoma on February 23, 1950, was held in the engineering auditorium, the guest speaker being H. J. Tomer of the metallurgical engineering department.

Tomer talked on the metals and their alloys and their importance in the world at the present time. He stated that the proper knowledge concerning metals and their alloys is an invaluable asset to the present-day engineer.

On February 7, the officers of the Petroleum Engineering Club for the spring semester were elected. They are Alton B. Slaybaugh, president; J. W. Tucker, vice-president; Pete Dickerson, secretary-treasurer; Bob True, manager of publicity; and William Liddell, social chairman.

At this meeting, plans for the petroleum engineering display for the engineering open house were discussed and O. C. Collins and True were appointed chairmen of the open house committee.

The Petroleum Engineering Club held its first meeting of the year on January 17. At this meeting, H. O. Harder, vice-president of production for the Sunray Oil Co. of Tulsa, gave an interesting talk on the "Inner Departmental Functions and Relationships of an Oil Company."

This was the last meeting in which E. G. Thurman presided over the organizations. He is immediate past-president. Thurman has now been graduated from the university and is employed by the Magnolia Petroleum Co. in West Texas.

The national convention of Pi Epsilon Tau, honorary engineering fraternity, was held at the University of Oklahoma on February 18, 1950. The convention was held in the Blue Room of the Student Union. Business and elections were held in the morning followed by a luncheon.

The first national officers of the Pi Epsilon Tau honorary engineering fraternity are, L to R, Councilmen John Campbell, LSU; and Bill Kellingworth, Texas Tech; President Paul Johnston, Texas Tech; Vice-President Paul Johnson, Tulsa University; and Secretary-Treasurer C. W. Flesher, Oklahoma University.

The purpose of the convention was to set up a national governing body for the organization. The national officers elected were Paul Johnston, president, formerly of the University and is now a faculty member at Texas Technological College; Paul Johnson, vice-president, Tulsa University; C. W. Flesher, secretary-treasurer, University of Oklahoma; and two councilmen, Bill Kellingsworth, Texas Technological College, and John Campbell, Louisiana State University.

The fraternity which was organized in 1947 at OU now has four additional chapters located at Tulsa University, Texas Tech, University of Southern California, and Louisiana State University.

The official delegates to the convention were Paul Johnston, Doyle McClennan, and Bill Kellingsworth from Texas Tech; John Campbell and Wilson Sanderson from LSU; Paul Johnson, Charles Novak, Tom McGinnis and Wayne Cox from Tulsa University; and John Sanders and Bill Tucker from OU. Southern Cal was not represented at the meeting. ★ ★ ★

Texas A&M

During the last few weeks the Petroleum Engineering Club at Texas A&M has had several guest speakers, including Lewis E. Young, former president of the AIME, and Douglas Ragland of the Humble Oil and Refining Co. Young spoke on the responsibilities of the young engineer in industry, giving a six-point program for success. Ragland discussed Humble's semi-automatic power operated drilling equipment, and the club is interested in taking a field trip to observe "Rig 30" in action. ★ ★ ★

Oklahoma A&M Student Branch

By Robert A. L. Harms

A delegation of members of the Mid-Continent Section of AIME was honored at the January meeting of the Student Branch at Oklahoma A&M College. Guests were C. V. Milliken, national director of AIME; Lloyd E. Elkins, immediate past-chairman of the Petroleum Branch; H. M. Cooley, Mid-Continent Section chairman; and J. P. Hammond, all of Tulsa, Oklahoma.

Milliken, also chairman of the State Board of Registration for Professional Engineers, spoke briefly on the history of AIME. He said that there are now more than 19,000 members in the organization, 3,000 of whom are members of student branches.

An alumni of Oklahoma A&M College, Milliken received his B.S. degree from that school and later attended the University of Pittsburgh where he was awarded an M.S. Recognition as an accomplished petroleum production engineer is evidenced by his receipt of the Anthony Lucas Medal for the outstanding contribution for the advancement of petroleum production engineering. He is now chief engineer of Amerada Oil Co.

Elkins, production research director of Stanolind Oil and Gas Co., stressed the value of associating oneself with an organization representing his individual field of engineering. Meeting men who have a common interest and who endeavor to continually improve themselves is only one of the many dividends reaped from such an association, he said.

Elkins' alma mater is the Colorado School of Mines. He has been associated with Stanolind for 16 years. At present, he is a member of the AIME Executive Committee and is also serving as vice-chairman of the main advisory committee for fundamental research on occurrence and recovery of oil for the American Petroleum Institute.

Cooley is associated with Bethlehem Steel Co. as a metallurgical engineer. Although not an actual petroleum engineer, he comes in close contact with oil field operations. It is his company's task to work hand in hand with the oil companies in designing better rigs, casings and steel equipment.

Cooley told the group of some of the activities of the Mid-Continent Section, one of which is the sponsoring of petroleum study periods at the University of Tulsa.

Hammond, of the Amerada Oil Co., told the members of the student paper contest which will be held in Tulsa April 28. One graduate and one undergraduate paper will be eligible for competition from each school in the area. Hammond is a graduate of the University of Tulsa and is a past-chairman of the Mid-Continent Section.

The remainder of the meeting was highlighted by the showing of a motion picture on Catalytic Cracking. New officers of the branch were to be elected at the next meeting of the group. ★ ★ ★

Members and honorary members of the Oklahoma A&M Student Branch get together following their recent meeting. They are, L to R, J. P. Everett of the Mechanical Engineering Department, J. P. Hammond, C. V. Milliken, Lloyd E. Elkins, H. M. Cooley and A. E. Schlemmer, also of the Mechanical Engineering Department at the school. Hammond, Milliken, Elkins and Cooley were made honorary members of the Branch.

University of Southern California

By D. D. Lloyd

Joseph Robinson, president of the Santa Fe Drilling Co., was guest speaker at the University of Southern California Student Associate Chapter meeting last semester.

An exceptionally active and interesting program was planned and executed by the executive officers of the student chapter during the fall semester. Dick Brazier, the president, and Bob Kazarian, the vice-president, with the willing help of program and activity committees, contacted two excellent guest speakers and located appropriate meeting places.

The first activity of the semester was a dinner meeting held at Scully's restaurant in West Los Angeles. All students enrolled in petroleum engineering or geology were contacted and urged to attend. The guest speaker was Joseph Robinson, president of the Santa Fe Drilling Co.; Robinson is a graduate of the University of Southern California, class of '29.

Robinson discussed the problems of a drilling contractor, the most important of which are cost of operations, labor relations and competition with other drilling companies. The importance of knowing costs and their sources was stressed emphatically by Robinson. His breakdown of actual expenses for labor, materials and maintenance of equipment was thorough and the data

Continued on Page 43

University of Tulsa

By H. A. Nedom and Ed Poulter

The University of Tulsa Chapter of the AIME opened the fall semester with an election of officers. They are H. A. Nedom, president; Tom Snodgrass, vice-president; Ed Poulter, secretary; Charles Rossman, treasurer; and John Buthod, activities chairman.

The group activities were initiated with an inspection trip through the Kerr Glass factory at Sand Springs, Oklahoma. Members witnessed the glass making process from the raw material "charge" to the finished glass jar.

Later in the semester, a tour was made through the National Tank Co.'s new plant in Tulsa. The tour was conducted by Alex Francis, assistant chief engineer of the company. The reaction of the members was very favorable after both inspection trips.

The Chapter's fall lecture program began on November 22. P. H. Bohart, assistant to the vice-president of the Gulf Oil Corp., spoke on employment opportunities for petroleum engineers.

On December 10, L. E. Elkins, director of production research for Stanolind, and 1949 chairman of the Petroleum Branch of the AIME, gave a talk entitled, "A Petroleum Engineering Degree—What Now?" In this talk, Elkins stressed the personal qualifications required and the proper attitude needed to make a success of one's vocation.

The third talk by C. V. Millikan, chief engineer of the Amerada Petroleum Corp., is planned. Millikan's talk will deal with the functions and membership requirements of some of the better-known engineering societies.

The organization would like to express its appreciation to A. W. Walker for his fine work as sponsor this year.

★ ★ ★

On the left are the officers of the student chapter at the University of Tulsa. From L to R, A. W. Walker, sponsor; H. A. Nedom, president; Tom Snodgrass, vice-president; Ed Poulter, secretary; Charles Rossman, treasurer; and John Buthod, activities chairman. On the right are pictured a group of members who toured the National Tank Co.'s plant in Tulsa.

The Drift of Things

...as followed by EDWARD H. ROBIE

Secretary AIME

Local Section Programs

Study groups, or discussion groups, to exchange opinions on subjects of specific professional interest have been most successful additions to the programs of some Local Sections, particularly in the Petroleum Branch. Those Local Sections that have not tried such meetings might well consider their possibilities.

One such group is being sponsored by the Gulf Coast Section of the Institute. A. G. Gueymard, secretary-treasurer, sends us the following brief description of its work: "At the present time we have established one discussion group, which is covering the subject of petroleum reservoir engineering. It is highly possible that other groups will be started in the future to study other phases of petroleum engineering. The present group meets once each month for a period of two to three hours. For each particular meeting a certain phase of reservoir engineering is set up for discussion, and one or more experts on this phase are available to conduct a discussion. Usually the speaker for the evening gives a general talk on the subject and then the floor is open for discussion by all concerned. The length of these meetings depends entirely upon the desires of the members present.

"The discussion group is particularly appealing to younger members of the AIME who are interested in gaining the knowledge and ideas of others on the subjects of their interests. We think the discussions are most beneficial and worthy of the amount of work necessary to keep the group going. The one drawback to this type of study group is that the discussion often becomes too elementary and detailed. Of course this undesirable situation must be prevented if possible by the directors of the group. The discussion group meeting is entirely separate from the regular monthly meeting of the Section; however, all AIME members are invited to attend."

Constant Turmoil

Writing items for this department that have anything to do with the news of the day has become increasingly difficult under the new publishing program, for what we have to say this sixth day of February will not be in the hands of some readers until the latter part of March. It seems fairly safe to say, however, that whenever this is printed a coal strike will either just have been settled, or one will be on, or one will be threatened, so a few remarks on the subject will not completely lack timeliness.

Undoubtedly John L. Lewis has done a lot to secure higher wage rates and shorter hours for the coal miners since he first began to take an interest in them. Also undoubtedly, the conditions under which large numbers of them have had to live have been bad, their work hard and dangerous, and their comparatively high wage rates misleading, for most of them do not know what it is to have a steady job five or six days a week throughout the year. And yet, sympathize though we do with them, we do not think the methods used by Lewis for their betterment are having the results intended. Over the years the increased cost of producing coal has forced prices so high that a good share of the former market has been lost to oil and gas and even to hydroelectric power. Another factor that has influenced some to turn to other fuels is the always present threat of supplies being cut off by a strike, a threat which rarely exists among producers of competitive fuels.

In fact, the market for coal has dwindled to such an extent that Lewis recently invoked the three-day week in an effort to prevent an undue accumulation of stocks. Now even at the high prevailing wage rates, miners cannot get along on the income from three days of work a week, and many of them have therefore been inclined to stay away from work entirely until a full week's work is available to them. Instead of doing something constructive to provide this work, Lewis continues to harp on ever-increasing wages, the present demand being for $15 a day instead of $14.05, and an increasing royalty to take care of their old age, which, if they had a good annual income, they should be able to provide for themselves out of earnings. It has been stated that it will take the average miner six to seven years at the 95c increase in the daily wage to reimburse him for the time he has lost on strike during the last year.

As the wage rate and royalty payments go up, so will the price of coal, which will result in less of it being used, which will mean less work for the miners, which will mean they will have to have higher wages for the time they *do* work, which is where we came in.

Now there is no particular point in talking about these things unless we have something constructive to suggest, so we hereby offer to the coal miners what we will modestly call the Robie Plan: Determine the average number of hours worked by the coal miners per year for, say, the last two years, and multiply this by the average wage rate, to get the average yearly earnings. Add a fixed amount, say 20 per cent to this total, and divide the sum by the number of hours that would be worked if the miners had the opportunity of working forty hours a week for fifty weeks in the year. This would give a

new average wage at which the miners would go to work. It would be far below the wage they are getting now — when they get it — but they would have steady work and their annual earnings would be higher by the 20 per cent. The cost of coal mining would drop considerably, and the price as well, so consumption should immediately begin to go up. It might take a little time for the market to absorb all that would be produced through a continuous forty-hour week, but the Government is so used to buying potatoes, and eggs, and fruit, and grain and other things that won't keep, that it shouldn't mind scattering a few stock piles of coal around the country. From cheap coal, gas and synthetic gasoline might be made, competitive with the products of the petroleum industry.

So there's the blue print. Those who know more about the coal industry than we do can work out the details.

Better Than the Atom Bomb

No sooner had the atom bomb, horrible as it was, become accepted in our minds as a possible back-to-the-wall resource in case of war than the hydrogen bomb suddenly appeared on the scene. This is supposed to be a thousand times as destructive as the A-bomb — just like a little chunk of the sun tossed on the earth, so we gather. Rightly, we think, it was decided that we should make it, but it will be quite another question as to whether we should ever use it. Certainly not use it first. And yet, if some one else uses it first, maybe we wouldn't be here to use it second. In any case, whether we have the H-bomb or just a passel of A-bombs, the prospect of war is now too horrible to ponder. Certainly some small percentage at least of what we are spending on military things should be spent on propaganda and methods of assuring peace. Armament races, throughout history, have led to war. It is a fond delusion that by making every effort to keep ahead of our competitors we can achieve "security" — a much overworked and misleading word.

It is heartening to see, therefore, in newspapers like *The New York Times* and the *New York Herald Tribune*, that columns of space are being given to the proposals to secure world peace and disarmament. Senator Brian McMahon, the highest Congressional authority on atomic energy, made a thrilling speech on the subject in the Senate on February 3. A month before, the House Foreign Affairs Committee unanimously voted to act on the world federation resolution, HCR 64. Nineteen Senators, headed by Charles W. Tobey, are behind a resolution declaring it to be the sense of Congress that the United States should promote the strengthening of the United Nations and "seek its development into a world federation open to all nations with defined and limited powers adequate to preserve peace and prevent aggression through the enactment, interpretation, and enforcement of world law."

At a hearing in Washington on February 3, Senator Wayne Morse described world federation as a "practical step we can take now in our search for lasting peace." Senator Claude Pepper said "the United Nations, through a world federation of nations, must be given powers to prevent war; power to enact, interpret, and enforce law."

Since publication of "The Anatomy of Peace" a few years ago, on which we commented at some length in these columns at the time, several other books have developed the subject further, among the most recent ones being "Peace or Anarchy" by Cord Meyer, Jr., and "The World Must Be Governed", by Vernon Nash. The several organizations promoting world peace finally united their activities in the United World Federalists, 7 E. 12th St., New York City 3, which for $1.50 a year publishes a monthly report of progress toward world federation entitled "World Government News." The idea has been spreading fast, and thousands of additional adherents have been stimulated by the prospect of the H-bomb. If a movement may be judged by the characters of its enemies, it might be added that Soviet Russia, the Hearst press, and the *Chicago Tribune* are violently opposed.

World federation and world law may not be the answer, but nothing so far advanced seems as promising. If we can spend fifteen billion dollars a year on armaments, certainly we can afford a billion or so to develop some more civilized and likely plan of securing our future happiness and prosperity than making the H-bomb. ★ ★ ★

AIME MEETING CALENDAR

MARCH

14 Delta Section, AIME

14 East Texas Section, AIME

15 Southwest Texas Section, AIME

21 Gulf Coast Section, AIME

23-25 Department of Geology, University of Kentucky, and Kentucky Geological Survey, symposium on minerals in southeastern U. S., University of Kentucky, Lexington.

APRIL

11 Delta Section, AIME

11 East Texas Section, AIME

4-5 Texas Mid-Continent Oil and Gas Association, Annual Meeting, Dallas

JUNE

26-30 ASTM 53rd annual meeting and 9th exhibit of testing apparatus and equipment, Atlantic City, New Jersey

OCTOBER

4-6 Petroleum Branch, AIME, New Orleans

FEBRUARY, 1951

19-22 AIME, Annual Meeting, Jefferson Hotel, St. Louis.

Engineers Joint Council Outlines Objectives

Engineers Joint Council is composed of the presidents and secretaries of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, and the American Institute of Chemical Engineers. At the year's end the total membership of the five Societies of EJC was 111,000.

A major internal step in the development of Council during the past year has been ratification by the governing bodies of the constituent societies of a formal constitution to replace the previous rather informal bylaws. The constitution states that the objectives of the Council shall be:

(a) To advance the general welfare of mankind through the available resources and creative ability of the engineering profession.

(b) To promote cooperation among the various branches of the engineering profession.

(c) To develop sound public policies respecting national and international affairs, wherein the engineering profession can be helpful through the services of the members of the engineering profession.

Upon that foundation, Engineers Joint Council, in its role as the cooperative, federating agency for the national societies representing the five basic branches of the profession, has been active in a wide variety of matters of national and international scope. Criteria for determining participation in any such matter are: (1) that it shall be of wide interest to the profession, and (2) that it shall be a matter having a direct impact on the profession or one regarding which it is believed that action by the profession can contribute to the public interest.

For years, EJC has been devoting study to stimulation of greater solidarity of the engineering profession. One of the most significant steps taken during 1949 was the calling of a conference, under the general auspices of Council's Committee on Unity of the Engineering Profession, for the purpose of developing specific recommendations as to measures for achieving further unity. Sixteen of the principal national engineering societies were invited to participate. At the meeting on October 20 fourteen societies were represented. A committee was appointed to study the relative advantages of several suggested courses of action and to report back to the conference at a meeting to be held early in 1950.

The small expense incurred in connection with the work of EJC is significant. Each year a budget is established and the necessary funds are prorated among the constituent societies in proportion to dues collections by each for the preceding fiscal year. Expenditures may vary within rather wide limits, depending on the character of projects undertaken, but for 1948 and 1949, the total each year was about $3900.

Disbursements for 1949 were broken down as follows:

General Operating Expense and Secretarial Service	$2498.28
General Survey Committee	697.23
Committee on Collective Bargaining	250.00
Labor Legislation Panel	376.49
Science Legislation Panel	73.52
Committee on International Relations	33.88
Total	$3929.40

That so much can be done with so little financial outlay is a tribute to the large number of men who have contributed vastly of their time and abilities in carrying out the programs of Council, thus rendering service to their profession, to their country, and to the world. The full extent of that service cannot be appreciated except by those who have been closely in contact with the work.

A listing of the names of the active committees of EJC is shown below:

Constitution and Bylaws
General Survey
Increased Unity in the Engineering Profession
Labor Legislation
Science Legislation
Engineers Cooperating in Medical Research
Engineers in Civil Service
Selective Service
Federal Income Tax
National Water Policy
Fuel Resources
National Engineers
International Relations
UNESCO
Consultative Status with the United Nations

An outline of the objectives and accomplishments of these committees is found in the EJC Annual Report, which may be had on request from the Secretary of EJC for 1950, E. H. Robie, AIME, 29 West 39th St., New York 18, New York. ★ ★ ★

WHITLEY HEADS NEW FIRM

B B M Drilling Co., a new concern, has been recently organized in Houston, Texas, to operate in the Mid-Continent and Southwest oil areas and is headed by Frank J. Whitley as vice-president and general manager.

The new company presently has four drilling rigs, three power and one steam, capable of drilling all depths to 15,000 ft. Current operations are now being effected in Western Oklahoma, West Texas and the Old Ocean Field of the Gulf Coast of Texas.

Whitley was graduated from Georgia Tech with a degree in mechanical engineering in 1933 and began his career in the industry as a roustabout. He resigned his position as assistant to the vice-president and manager of operations of J. S. Abercrombie Co. in Houston to head the new firm. ★ ★ ★

EXECUTIVE AND FINANCE COMMITTEES DISCUSS BUDGET AND BYLAWS CHANGES

Matters discussed by the Executive and Finance Committees of the Institute at their meeting on January 20, 1950 at Institute headquarters were largely of a routine or minor nature, the more important discussion being reserved for the Board meeting on February 12.

A preliminary budget for 1950 was reviewed, indicating a small balance in the black expected for the year, following four years in which expenditures exceeded income by a substantial margin. A balanced budget will be attained chiefly through an expected increase of some $55,000 in dues receipts and some $58,000 in advertising.

The committees voted to extend to Junior Members who have been on the rolls for ten consecutive years, and who applied for a change of status to Associate Member or Member before December 31, 1949, the privilege of such change of status without the payment of an initation fee. Previously the limiting date was that of *election* rather than of *application*. Similarly, it was voted that the privilege of election as a Junior Member be extended to those who apply for such membership before their thirtieth birthday, instead of to those who are *elected* before they are thirty years old. A change in the bylaws to make this ruling permanent was recommended to the Board, as stated in another column. It was felt that a young man has done his part if his application was made before the time limit expired, and that he should not be responsible for the time consumed in the election procedure.

Another change proposed in the bylaws, which is expected to be acted upon at the Board meeting in April if one is held, has to do with Affiliated Student Societies. It has been found impractical to enforce the distinction between Student Chapters, which are composed entirely of Student Associates, and other student societies composed of many students who are not Student Associates, so it is proposed in future to call all recognized student societies Student Chapters, only the officers of which would be required to be Student Associates. Another item of interest to students was the committee's vote that all five of the national student prizes for the best papers be for $100. Heretofore one of the two graduate prizes was for $50. The student prize winners for 1949, who will receive their awards at the Annual Meeting, are as follows, the first two being graduate prizes:

John A. Harrison, ($100) for his paper, "Progress in Mechanization in Underground Coal Mines", entered by the Chicago Section.

L. R. Kalman, ($50) for "Diffusion in Iron and Steel, a Literature Survey", also Chicago Section.

Everett O. Bracken, ($100) for "The Christensen Sillimanite Deposit Southeast of Dillon, Montana", Montana Section.

Continued on Page 43

PROPOSED BYLAWS CHANGES

Notice is hereby given that at its meeting on January 20, 1950, the Executive and Finance Committees voted to bring before the Board at its meeting next following that of February 13 the following changes in the bylaws:

Substitute for the second and third sentences of Article 1, Section V, the following: "He shall be not more than thirty years of age at the time of his application, and shall not remain a Junior Member beyond his thirty-third birthday."

The effect of the amendment is to make the date of application rather than the date of election the limiting factor in the election of Junior Members, who may thus be permitted to attain their thirtieth birthday between the time of application and the time of election.

An amendment is also proposed to eliminate the distinction between Student Chapters and other Affiliated Student Societies, all of which would hereafter be known as Student Chapters. The proposed amendment is as follows:

In Article XI, Section 4 of the bylaws, replace the words "Affiliated Student Society" wherever they occur by the words "Student Chapters," the words "Student Society" by "Student Chapter," and the word "Society" by "Chapter." Further, delete the last paragraph of this Section reading "An Affiliated Student Society whose bylaws require all members to be Student Associates of the Institute may use the designation 'Student Chapter of AIME'."

Proposed for Membership

Total AIME membership on Sept. 30, 1949, was 15,988; in addition 4427 Student Associates were enrolled.

ADMISSIONS COMMITTEE

James L. Head, Chairman; Albert J. Phillips, Vice-Chairman; George B. Corless, T. B. Counselman, Ivan A. Given, Robert L. Hallett, Richard D. Mollison, and John Sherman.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.

In the following list C/S means change of status; R, reinstatement; M, member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

ALABAMA

LEWISBURG—Sides, Judson B. (M).

RUSSELVILLE—Britton, Sam Abney. (R,C/S—JA-M).

ARIZONA

MORENCI — Eckhouse, Robert Hermann. (C/S—S-J). Heyde, John Albert. (C/S—S-J). Moolick, Richard Terrence. (C/S—S-J).

ARKANSAS

LITTLE ROCK—Foxhall, Harold B. (M).

CALIFORNIA

BISHOP—Carpenter, Robert Dickerson. (C/S—J-M).

BURLINGAME — Shafer, William L. (M).

LONG BEACH — Wilson, James W. (M).

LOS ANGELES—Kohn, Arthur Frederic, Jr. (C/S—J-M). Morris, Joel Maurice. (C/S—S-J). Mott, Jack Sheridan. (J). Taves, Max John. (C/S—J-M).

REDONDO BEACH—Borkovich, George John. (C/S—S-J).

SAN FRANCISCO — Hatton, Joseph Herbert. (R,C/S—J-M).

SAN MARINO—Irwin, Emmett MacDonald. (M).

WHITTIER—Smith, Charles Edward. (C/S—J-M).

COLORADO

GILMAN—Maloit, Frank James. (R-M). Radabaugh, Robert Eugene. (M).

GOLDEN—Aitkenhead, William Charlton. (R-M).

HAMILTON—Cutler, William Gifford. (J).

CONNECTICUT

HARTFORD—Kycia, Michael Anthony. (C/S—S-J).

WATERBURY — Blank, Albert Irving. (C/S—J-M).

WESTPORT—Batchelor, Mead Whitlock. (M).

DELAWARE

WILMINGTON—Poel, Harlan James. (M).

FLORIDA

MULBERRY — Barnett, Grady. (M). Fuller, Robert B. (M). Loehr, Henry Turner. (M). Tillotson, Irving Smith. (M).

IDAHO

BOISE—Pothier, Oscar Edward. (C/S—J-M).

KELLOGG — Haffner, Robert Louis. (J).

MULLAN—Hakala, Oiva Waldemar. (C/S—S-J).

NORTH POCATELLO—Spencer, Emmett Luther. (C/S—J-M).

ILLINOIS

CENTRALIA — Walker, Bobbie Philbrick. (J).

CHICAGO — Carney, Dennis Joseph. (C/S—S-J). Niotis, Demetrius John. (M). Robertson, William Donald. (C/S—J-M).

HIGHLAND PARK—Robbins, F. Peter. (C/S—J-M).

MT. VERNON—Brehm, Clarence Eckhart. (M).

ST. JACOB—Swanbeck, Leonard William. (M).

WILMETTE—Davis, Philip David, Jr. (J).

KANSAS

BAXTER SPRINGS—Childress, Harold Lyle. (M). Landis, Miles Benjamin. (M).

ELLINWOOD — Lamar, James Riley. (J).

LYONS—Sawvel, Glenn Carl. (C/S—S-J).

KENTUCKY

PAINTSVILLE—Baker, John Augustus. (C/S—S-J).

LOUISIANA

HOUMA—Whitman, Harold Anthony, Jr. (C/S—S-J).

LAFAYETTE—Greenley, Richard Edward. (C/S—S-AM).

MASSACHUSETTS

CAMBRIDGE—deBruyn, Philip Louis. (C/S—J-M). Paranjpe, Vijay Gopal. (C/S—S-J).

GARDNER—Moline, Gordon Herbert. (C/S—S-J).

HAMILTON—Rice, Charles G. (AM).

HYDE PARK—Dunn, William J. (M).

WALTHAM—Shank, Maurice Edwin. (C/S—S-J).

MICHIGAN

CRYSTAL FALLS—Royce, Josiah. (C/S—J-M).

DETROIT — Chapman, Richard D. (C/S—J-M). Timmons, George A. (C/S—J-M).

HOUGHTON—Spiroff, Kiril. (R-M).

ISHPEMING—Beutner, Edward Louis. (M). Westwater, James Stuart. (C/S—J-M).

MINNESOTA

BRAINERD—Knudsen, Louis. (M).

DULUTH—Campbell, Robert Emerson. (J). Hagen, Robert Earl. (C/S—S-J).

VIRGINIA—Manseau, Horace Francis, Jr. (M).

MISSOURI

FULTON — Reinkensmeyer, Norman William. (J).

HANNIBAL — Knopp, Charles Roger. (J).

INDEPENDENCE — Steinheider, Wilt Henry. (C/S—J-M).

ROLLA — Kershner, Karl K. (M). Rosenbaum, Seymour. (C/S—S-J).

WEBB CITY — Kirk, Whitson John. (M).

MONTANA

ANACONDA—Finnegan, Walter Daniel. (C/S—S-J).

BUTTE—Mott, William Henry. (AM).

NEVADA

TUNGSTEN—McGuire, Philip C. (C/S—J-M).

NEW JERSEY

ARLINGTON—Perch, Michael. (C/S—J-M).

BOUND BROOK—Brigden, George I. (AM).

ELIZABETH—Leslie, William Cairns. (C/S—S-J). Morton, Byron Benson. (M).

RUTHERFORD—Nissley, Roy R. (AM).

NEW MEXICO

BAYARD—Eastman, Frank Erastus. (C/S—J-M).

CARLSBAD — Barr, Richard Cromer. (J). Blanchard, John Guion. (M). Deviny, William Michael, Jr. (J).

LOS ALAMOS — Wensch, Glen William. (C/S—S-AM).

NEW YORK

BEDFORD HILLS — Franceschini, Victor William John. (C/S—J-AM).

BUFFALO — Chestnut, Albert Heath. (C/S—J-AM). Jarvis, Herbert O. (M).

CHAPPAQUA—Keith, Stanton Baker. (C/S—J-M).

CRESTWOOD — Jemal, Emile Joseph. (M).

DELMAR — Malmgren, Carl Eilertz. (C/S—J-M).

HUNTINGTON — Briggs, Fred, Jr. (M).

KENMORE — Kline, James Dickey. (M).

LARCHMONT—Henault, Emil August. (AM).

NEW YORK — Barker, Alexander Crichlow. (AM). Dohm, Christian F. (M). Gervais, Arthur Joseph. (AM). Hoover, William Harold. (AM). Ingersoll, Vernon LaForge. (AM). Rosenbaum, Joseph. (AM).

STAN LAKE—Durocher, Roland Edward. (M).

NORTH DAKOTA

MICHIGAN—Jefferies, Robert L. (C/S—S-J).

OHIO

CLEVELAND HEIGHTS—Cox, Merrill. (M).

COLUMBUS—Frost, Paul Davis. (C/S—J-M).

ELYRIA—Witte, Otto. (AM).

OKLAHOMA

BARTLESVILLE — Smith, R. Vincent. (M).

CHICKASHA — Walker, N. Morgan. (R-M).

DUNCAN—Olson, Cleo Charles. (M).

OKLAHOMA CITY—Gogniat, Stephen. (M). Hegglund, Martin Oliver. (C/S—J-M). Johnson, Charles Teddy. (C/S—S-J). Patty, Duncan Victor. (R,C/S—S-J).

TULSA—Garlington, Raymond Ellis, Jr. (J). Moore, Wesley Warren. (M). Pearson, Alvin Jerrold. (J). Renberg, Kenneth. (C/S—S-J).

OREGON

CORVALLIS — Hess, Harold DeWitt. (C/S—S-J). Watkins, Kenneth Oral. (R,C/S—J-M).

PENNSYLVANIA

EVANS CITY—Rape, Sylvester Herman, Jr. (C/S—S-J).

JOHNSTOWN—Howell, John P. (C/S—J-M).

PHILADELPHIA—Bounds, Ardrey Middleton. (M).

PITTSBURGH—Blood, William Wooster. (M). Giusti, Gino Paul. (J). Snouffer, Richard Dun. (C/S—J-M). Snyder, George M. (C/S—J-M). Wishowski, I. Stanley. (M).

POTTSVILLE—Condit, Merlyn Edwin. (M). Quin, Robert Augustus. (J).

SPANGLER—Williams, Walter Dewey. (M).

STATE COLLEGE—Hill, Robert Grant. (C/S—AM-M).

TEMPLE — Eberly, Warren Samuel. (M).

YORK — Norris, Bertrand Saunders. (C/S—J-M).

SOUTH CAROLINA

TRAVELERS REST—Johnson, Henry S., Jr. (C/S—S-J).

TEXAS

ALBANY—Smith, Bertram Leon, Jr. (C/S—S-J).

AUSTIN—Barber, Harry Curtis. (J).

BIG LAKE—Abbott, William Gordon. (J).

BOWIE—Koontz, Roderick W. (R, C/S—S-J).

CALVERT—McMillan, Frank Ney, Jr. (J).

CORPUS CHRISTI — Summers, Paul Howard. (J).

EL PASO—Stillinger, Dudley Loomis. (J).

FORT WORTH—Athanas, Gus. (C/S—J-M). Elner, Ray. (C/S—AM-M). Morrison, Paul W. (M).

HOUSTON—Bailey, Charles Woodrow. (M). Clegg, Millard F. (M). Holman, Russell Wesley. (C/S-J-M). O'Rourke, Thomas Floyd. (C/S—J-M). Pickles, William M., Jr. (M). Quinn, Julian William. (M). Shearer, Louis Hollis. (C/S—J-M). Sheets, Martin Meredith. (M). Sloan, J. Paul. (M).

IRAAN—Brack, John Raymond. (C/S—S-J).

LEVELLAND—Christner, Jimmie Drue. (J).

LUBBOCK — Johnston, Paul Shirley. (C/S—S-J). Livermore, George Pogue. (R,C/S—S-J).

LULING — Bilderback, Ervin Glen. (C/S—S-J).

MIDLAND—McCaskill, Neal. (C/S—J-M). Priddy, Charles Horne. (J). Ramage, Bruce Granville. (M).

ODESSA — Kendall, Ernest Clayton. (C/S—AM-M). Lovelady, Isaac William. (M).

PAMPA—Bauer, Roy Maurice, Jr. (C/S—S-J).

SILSBEE—Williams, Walter Lazenby. (C/S—S-J).

SUNDOWN—Hamann, Lloyd Arthur. (C/S—S-J). Powers, Walter Daniel. (R,C/S—J-M).

UTAH

BINGHAM CANYON — Evans, Hugh Williams. (C/S—S-J). Norden, Joseph Alfred, Jr. (M).

CEDAR CITY—Morgan, Ronald Chas. (C/S—S-J).

LARK — Brownson, Lloyd Daniel. (C/S—S-J).

PROVO — Burgin, William Herman. (C/S—J-M).

SALT LAKE CITY—Haley, Fred S. (C/S—J-AM). Kirkland, Archie Glover. (C/S—J-M).

VIRGINIA

ARLINGTON—Reifsnyder, Thomas B. (C/S—S-J).

WASHINGTON

GOLDENDALE—Ellett, Richard D. (J).

HOLDEN—Newman, Joseph Melvin. (C/S—J-M).

METALINE FALLS — Scott, Marshall Wellington. (C/S—AM-M).

WEST VIRGINIA

CHARLESTON—Rees, Thomas B. (C/S—J-M).

GLENVILLE — Young, Donald Bell. (C/S—J-M).

MONTGOMERY — Mohtashami, Mansoor. (AM).

WHEELING — Boyd, John Thomas. (M).

WISCONSIN

MADISON—Tupas, Mateo Hernandez. (C/S—J-AM).

WYOMING

ROCK SPRINGS—Simon, Jack Thomas. (C/S—J-M).

ALASKA

NOME—Jones, Daniel Amasa. (C/S—S-J).

ALBERTA

LETHBRIDGE—Livingston, Robert Donald. (M).

BRITISH COLUMBIA

CHAPMAN CAMP—Ruffle, James Arthur. (C/S—J-M).

MANITOBA

FLIN FLON—Carr, John David. (M).

ONTARIO

BURLINGTON—Warner, Kenneth Melville. (C/S—S-J).

KIRKLAND LAKE — Hopper, Charles Houghton. (M).

PORCUPINE—Schmitt, Donald E. G. (C/S—J-M).

TORONTO — Loree, Robert Jarrell. (C/S—S-J).

QUEBEC

MONTREAL—Walker, Walter Samuel. (C/S—J-M).

NORANDA—Heino, Kauko Hendrick. (C/S—S-J).

NORRIE — Lambert, Donald Platt. (C/S—J-M).

VERA CRUZ

COATZACOALCOS — Fackler, William Corliss. (C/S—J-AM).

GUATEMALA

COBAN A.V.—Tufts, John Marshall, Jr. (C/S—J-M).

BOLIVIA

LA PAZ—Salter, Russell. (R.C/S—J-M).

PULACAYO—Eck, John. (M).

CHILE

CHUQUICAMATA — Becker, Robert Charles. (R.C/S—J-M).

POTRERILLOS—Brinley, Edward Hermann. (C/S—S-AM).

ECUADOR

QUITO—Miller, Robert M. (C/S—S-J).

VENEZUELA

MARACAIBO — Dominguez, Jose Rafael. (C/S—J-M).

FRANCE

SAINT-SERVAN ILE ET VILAINE—Marchal, Jacques Henri. (C/S—S-J).

GERMANY

FRANKFURT A M. — Thieler, Erich Gustav. (R-M).

ITALY

TORINO—Debenedetti, Arturo. (M).

NORWAY

OSLO — Poulsen, Arthur Otterbeck. (M).

TRONDHEIM — Smedsland, Tryggve. (C/S—S-J).

SWEDEN

STOCKHOLM—Kuo, Ke-hsin. (J).

NORTHERN RHODESIA

LUANSHYA — Smith, James Talbot. (C/S—S-J).

UNION OF SOUTH AFRICA

JOHANNESBURG — Papenfus, Edward Bossau. (M).

VIRGINIA — Muller, Thomas Frederik. (M).

SAUDI ARABIA

ABQAIQ—Smith, Hugh Ferries. (C/S—J-AM).

TURKEY

KARABUK — Ulubay, Ali. (C/S—S-M).

JAPAN

TOKYO—Nishiwaki, Tikawo. (M).

VICTORIA

MELBOURNE—Wiebenga, William Alexander. (C/S—J-AM).

PHILIPPINE ISLANDS

BAGUIO — Fertig, Claude Edward. (M).

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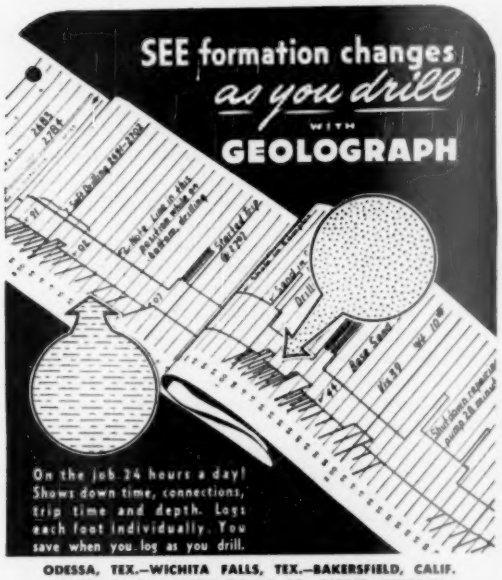

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— Personals —

CECIL A. HAMMAN has joined S. C. Yingling, an independent operator at Evansville, Indiana. After graduating from Purdue and the University of Texas, he was employed by the Ohio Oil Company. Later he joined The Pure Oil Company and remained with that company until his recent change.

+

DAVID C. MCLAUGHLIN, engineering representative for Bethlehem Supply Company at Dallas, Texas, became oil field engineering representative for Bethlehem Steel Export Corp. with headquarters in New York City on January 2. McLaughlin joined Bethlehem Supply Company at Dallas in 1939.

+

JAMES R. HERRINGTON, JR., is now connected with Otis Pressure Control, Inc., as a field engineer in the caliper department located at 6705 Navigation Blvd., Houston 11, Texas.

+

RALPH A. HOCKENSON has gone to Tulsa, Okla., to work for the Carter Oil Co., in charge of secondary recovery operations. His new address is 3836 S. St. Louis, Tulsa, Okla.

+

ALBERT J. Z. CAAN has been transferred from Caracas, Venezuela, to the exploration department of the Socony-Vacuum Oil Company in New York City.

+

FRANK P. DONAHUE, formerly head of the oil loan department, National Bank of Commerce, Houston, and JOSEPH B. ZICK, formerly with Danciger Oil and Refining Co., Fort Worth, Texas, are now associated with Alec M. Crowell, Natural Gas Consultants, Carondelet Building, New Orleans. They will move to the California Company building at 1111 Tulane Avenue, New Orleans, when that edifice is completed about October 1, 1950.

South Plains Sub-Section

Continued from Page 25

face production unit, equipped with packer and O-ring seals, is hydraulically seated in the well or surfaced by merely operating a four-way valve located at the well head.

When brought to the surface, it is caught in a special device which is built into the four-way valve assembly. This arrangement permits the pumper to replace the unit, generally within an hour, and without the necessity of pulling tubing.

At the surface, an engine driven triplex pump delivers power oil, generally clean crude, through a header and thence through a one-inch high pressure line to the well. Either a regulation of the speed of the triplex pump or the use of a pressure regulator at the header may be employed as a means of governing the speed of the subsurface production unit.

This also means that production rates will also be varied in the same manner, Ihrig said. The production rate may also be varied by inserting a plunger in the production assembly of the subsurface unit with a diameter larger or smaller than that of the engine assembly piston.

Pump speed and other operating characteristics may be determined by interpreting fluctuations of gauge pressures. A decline in pressure on the power oil may indicate that the well has pumped off, the production assembly has plugged, or that the well fluid is extremely gassey.

If any of these conditions develop, the subsurface unit would operate at excessive speeds due to the higher pressure differential existing between the engine assembly intake and the production assembly discharge. For this reason, a governing feature is built into the engine valve assembly to dampen excessively rapid valve action.

Ihrig pointed out that calculation of power requirements for Kobe installations are generally based on an overall mechanical efficiency of 60 per cent although efficiencies up to 90 per cent have been reported. Kobe research engineers are currently testing new alloys and designs for use under different operating conditions, he said.

One of the most serious problems with which they are faced in the West Texas area is that of combatting corrosion.

★ ★ ★

Kansas Section

Continued from Page 24

mined in one or more wells at the beginning of the project.

The Section held its first meeting of the year on January 31 at the Country Club of Eureka. Fred Kluck, Ohio Oil Co., Eureka, the Section's vice-chairman for Eastern Kansas, arranged the dinner and program which was attended by 65 members and guests.

In the absence of W. F. Brown, chairman of the Section, Kluck read a letter from P. P. Manion of the Mid-Continent Section which invited the Kansas Section to join the Oklahoma and Mid-Continent sections in publicizing and jointly sponsoring a student contest to be held at the regular joint meeting of their sections, tentatively scheduled for April 28. This contest will be open to student AIME groups of the University of Tulsa, University of Oklahoma, Oklahoma A&M College, University of Wichita and University of Kansas.

Kluck recalled that one of the newly founded Kansas Section's first actions last year was to express its approval of such contests and to establish a fund for awards to be given to the authors of the best papers. The Kansas Section therefore is prepared to join in sponsoring the joint student contest and will so advise the originators of the plan. Kluck then introduced Pate as speaker.

V. J. (Mike) Mercier, Section delegate represented the group at the national meeting in New York last month. He announced that Tom Orr, executive secretary of the Kansas Independent Oil and Gas Association, who spoke before the Section in December, 1949, about the Hoover Commission Report presented the same earnest plea for the adoption of this report at the national convention.

The next meeting of the Kansas Section was to be in Great Bend, Kan., in the latter part of February. Speaker was to be Louis G. Chombart, manager of the Kansas Division, Schlumberger Well Surveying Corp., in Wichita, Kan.

★ ★ ★

Junior Group

Continued from Page 26

thixotropic if its behavior varies with time.

Cardwell then displayed a number of actual curves of drilling fluids at equilibrium. Bentonitic fluids displayed characteristics more nearly like water than field muds which are associated with high gell strengths.

The February meeting at which Cardwell spoke was opened by Chairman Norman B. Clark who explained a new policy of charging an additional 25 cents for dinner to non-members. The change was adopted by the executive committee to help defray mailing cost to non-members. The chairman then introduced the 1950 Junior Group officers and announced that he is being transferred to Coalinga, making it impossible for him to continue work with the group. An election was to be held at the group's March meeting to fill the vacancy created by the transfer of Clark.

Continuing with his talk, Cardwell, a graduate of the California Institute of Technology in Chemical Engineering, discussed drilling problems affected by viscosity. He said the swabbing effect of pulling the drill pipe out of the hole is caused by a pressure drop at the bottom of the hole which occurs when the drilling fluid shearing rate does not reduce the shearing stress in proportion.

The opposite of this effect takes place when running in the hole, he added. Viscosity is important to a small extent in bringing cuttings up to the surface. It is generally believed that large chunks of shale are more readily brought up to higher viscosities. The high shearing rates present in normal drilling fluid flow cause it to act like a Newtonian fluid. The important variables affecting cuttings return are density and velocity. Most of the pressure loss, about 80 per cent, in a mud circulation system occurs in the drill pipe. The energy losses are not proportional to viscosity, but dependent on density and average velocity of flow.

When is viscosity important in the field? Cardwell said that it is definitely not important where shear rates are high. Viscosity measurements in the field have to a large extent had tremendous value in standardization of methods. The Marsh Funnel and the Stormer Viscosimeter are now widely used methods of measurements, he said. He added that Standard Oil Co. is trying to develop viscosity measurements that are more vigorous and accurate. One such instrument, that is now being tested is a continuous recording viscosimeter.

At the March meeting of the Pacific Junior Group, Ernest O. Kartinen of the Signal Oil and Gas Co. was to describe the moving of a complete drilling rig from the California mainland across open water to Santa Rosa Island. Colored motion pictures were to be presented by Kartinen to illustrate the methods used to get the rig onto the island and to the drilling location. A complete description of the operation will be given in the April JOURNAL.

★ ★ ★

Executive and Finance Committee

Continued from Page 38

William H. Humphries, ($100) for "The Effect of Copper and Nickel Upon Rate of Sulphur Transfer", Pittsburgh Section.

Horace K. Thurber, ($100) for "Sodium Sulphate, a Possible New Utah Industry", Utah Section.

The Committee of Award was composed of Clark B. Carpenter, chairman, E. F. Schramm and William A. Staab. Entries were limited to prize-winning papers of the Local Sections that conducted contests.

A prize of $25 was authorized to be paid to Jason E. Everts, of Salt Lake City, for designing the best "key" to be made available to Student Associate members of Student Chapters.

The Committees recommended to the Board that the office of Controller be established, and that George I. Brigden, vice-president and treasurer of the St. Joseph Lead Co., be appointed to the office.

Revised bylaws for the new Mining, Geology, and Geophysics Division of the Institute were approved, subject to the approval of that Division.

Institute representatives on Engineers Joint Council for the coming year were named as follows: L. E. Young and Herbert G. Moulton, as "the most available past Presidents", with D. H. McLaughlin and Edward H. Robie, ex officio. It was noted that Young would be president of EJC for the coming year and Robie secretary.

Various AIME representatives were named as follows: Harvey S. Mudd re-appointed to the Rocky Mountain Income Committee for three years. C. B. Sawyer to succeed C. H. Mathewson on the council of the American Association for the Advancement of Science. Paul Weir at the presentation of the Washington Award for 1950 to Wilfred Sykes on February 27. Scott Turner to succeed himself on the Hoover Medal Board for six years. ★ ★ ★

University of Southern California

Continued from Page 34

he gave were in some cases astonishing to the group.

A second dinner meeting was held in November at Old Dixie in Los Angeles. Barton Cater, manager of the regional personnel office for Standard Oil of California, was the guest speaker. Carrol M. Beeson, associate professor of petroleum engineering at the University of Southern California, introduced Cater, whose topic was basic safety in the oil industry. He used a prepared set of charts and diagrams that enabled him to present graphically as well as verbally his expert advice and information. He presented to the group typical procedures for safety measures and the chain of command where safety responsibility must lie in an efficient organization. At the end of his talk Cater distributed supervisor's guides for making safety inspections and blank employer's reports of industrial injury for the members to study and evaluate.

During December two field trips were made to the Torrance refinery of the General Petroleum Corp. The tours were conducted by operating engineers and department heads. The T.C.C. units, the new coker plant installation and the spectroscopic gas analyzer were outstanding objects of interest and discussion. A brochure describing the operation of the refinery and a simplified flow sheet were given to all the students for future reference.

The semester activities were terminated by a dinner dance at Vivian Laird's restaurant in Long Beach. The first function of its kind to be held by the Student Chapter, it served as an excellent opportunity to acquaint the members and their wives socially. ★

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 601 Continental Building, Dallas 1. Show return address on envelope. These replies will be forwarded unopened, and no fees are involved.

PERSONNEL

♦ Graduate, M.S. degree June, 1950, 28, married; would like position in micropaleontology laboratory with oil company, this country or overseas. Code 122.

♦ Petroleum Engineer, recent graduate University of Minnesota, 24, single, inexperienced; desires position as petroleum engineer trainee, foreign or domestic. Code 123.

♦ Geologist, B.S., 23, single, veteran, desires employment in exploration department of oil company in either domestic or foreign service. Radar experience. Code 125.

♦ Petroleum engineer with B.S. degree in mining engineering, 31, married; approximately five years petroleum engineering experience in production and development in Rocky Mountain area with major companies; desire connection with strong, aggressive independent in petroleum engineering or production departments, U. S. or foreign. Code 124.

♦ Young geologist desires position with petroleum or mining company; married, 23 years of age, B.S. degree in geology; will consider anything in U. S. or foreign. Code 126.

♦ Petroleum engineer, M.S. degree, 34, one year postgraduate studies, several years practical experience in drilling, mud control, field and subsurface geology, electrical surveys and well logging, and production of oil seeks connection with an oil company, well service company, drilling contractor or consulting geologist, where his abilities and qualifications could be fully utilized. Available on one month's notice. Code 127.

POSITIONS

♦ Petroleum geologist-sedimentologist, for research in secondary laboratory in Appalachian area; preferably with university research experience or graduate degree. Code 519.

♦ Petroleum engineering experts with wide knowledge of drilling or refining industries are wanted by the Egyptian government. Renewable contracts for a minimum of one year. Return trips paid. Salary and expenses in Egypt depend on qualifications. Reply directly to Ibrahim E. Imam, Commercial Secretary, Royal Egyptian Embassy, Washington, D. C. ★ ★ ★

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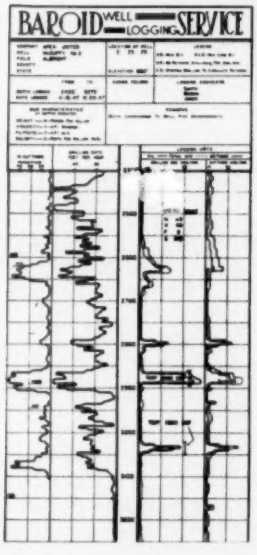

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Date	Specific Productivity Index	Cumulative Production (bbls)
March 29, 1939	.02250	17,700
October 3, 1943	.00682	385,900
January 28, 1947	.00284	621,100

During the 94 months between the date of the first SPI (March 29, 1939) and the date of the last one (January 28, 1947), total production was 603,400 bbls., or a *monthly average of 6419 bbls.*

WELL "B" drilled with WATER BASE MUD

Date	Specific Productivity Index	Cumulative Production (bbls)
August 21, 1940	.00714	15,100
August 22, 1943	.00258	148,200
August 29, 1947	.00129	275,300

During the 84 months between the date of the first SPI (August 21, 1940) and the last one (August 29, 1947), total production was 260,200 bbls., or a *monthly average of 3,098 bbls.*, less than half!

Both wells were drilled in almost identical formations

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RELATIVE PERMEABILITY TO GAS

W. J. LEAS, MEMBER AIME, **L. H. JENKS,** AND **CHARLES D. RUSSELL,** THE CARTER OIL CO., TULSA, OKLAHOMA

ABSTRACT

A detailed description is given of an experimental method for determining relative permeability of porous media to gas. Results are presented for natural and synthetic cores. The experimental data for two and three phase systems are compared. The reproducibility of the equilibrium gas saturation is demonstrated and the effects due to a variation in rate of gas flow are discussed. An attempt is made to correlate total permeability and rock textural factors with relative permeability to gas. Capillary pressure curves obtained simultaneously with the relative permeability curves are shown to be equivalent to those obtained in conventional displacement cells.

INTRODUCTION

The advances in petroleum reservoir technology during the past decade have made increasingly apparent the desirability of a simple, rapid, reliable method for obtaining relative permeability data on small cores. Such data are needed in order to study fluid mechanics in porous media and for the more refined reservoir behavior prediction calculations now under development.

The early experimental work in this field was done by Wyckoff and Botset[1] who measured relative permeabilities for gas-liquid mixtures flowing through

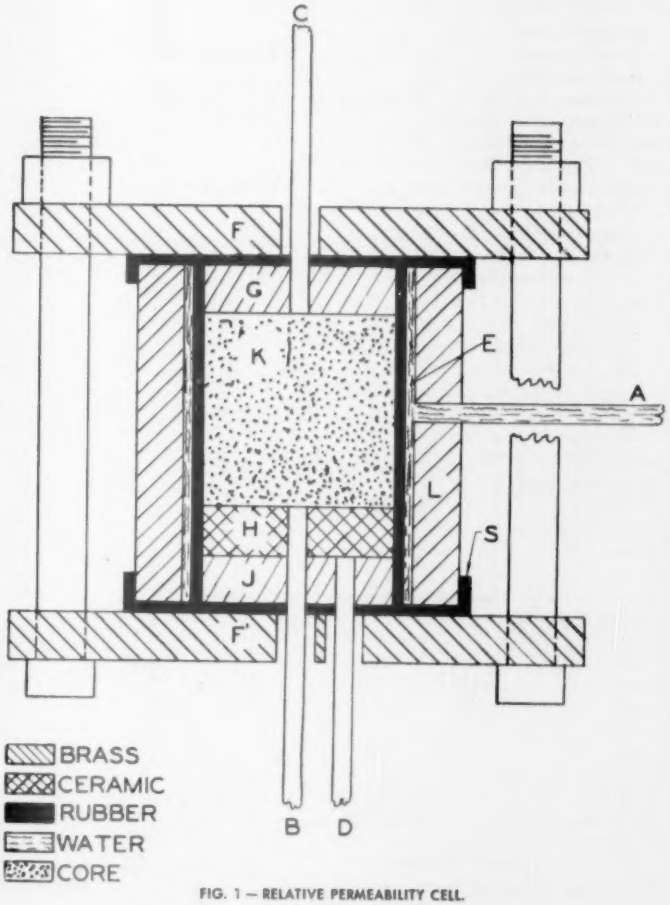

FIG. 1 — RELATIVE PERMEABILITY CELL.

[1] References given at end of paper.

Manuscript received at the office of the Petroleum Branch October 1, 1949. Paper presented at the Petroleum Branch meeting in San Antonio, October 5-7, 1949.

unconsolidated sands, and by Hassler, Rice, and Leeman[3] who measured the effective permeabilities to gas on small Bradford cores saturated with varying amounts of stationary liquid. Extensive studies have been made by Leverett[4] and Leverett and Lewis[5] on the behavior of fluids in packed columns of unconsolidated sand in which the two phases, oil and water, and the three phases, oil, water, and gas, were flowing in the sand simultaneously. Botset[6] extended his techniques to consolidated Nichols Buff sandstone and more recently Morse, Terwilliger, and Yuster,[7] and Henderson and Yuster[8] have developed relative permeability apparatus for small core samples. Hassler[9] has patented a method and apparatus for relative permeability determination which makes use of semi-permeable barriers to maintain a pressure difference between fluid phases.

The experiments of the above investigators may in general be divided into two types depending upon whether or not a difference in pressure is mechanically maintained between the gas and liquid phases. In the experiments reported by Botset, Leverett, and Yuster et al the gas and liquid are allowed to flow through the core at the same pressure gradient and hence are classified as being those in which no difference in pressure is maintained between phases.

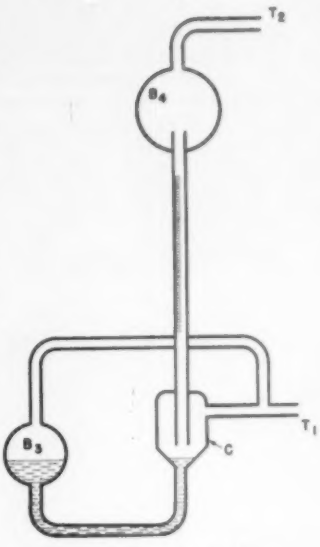

FIG. 2 — CROSS-SECTIONAL VIEW OF FLOWMETER.

In such experiments K_g and K_l are affected by the rate of flow.* At low rates, the end effect is quite pronounced and its effect is propagated back into the core to an appreciable extent. This and other rate effects limit this type experiment to a range of flow rates which may not correspond to reservoir rates.

To the authors' knowledge only limited data are available which have been obtained with the Hassler[9] method or modifications thereof.[10] In principle the elements necessary for establishing and maintaining a difference in pressure between the flowing phases are present in this technique. The geometry of the porous rings at the ends of the core, however, leaves much to be desired insofar as uniformity of saturation within the core is concerned. Moreover the auxiliary equipment appears to be unduly complex and not easily adaptable for inexpensive routine use.

The work presented in this paper has been directed toward overcoming the objections of the Hassler method. A cell has been designed which permits the maintenance of a pressure difference between the two phases, gas and oil; the oil phase is held immobile at each particular saturation while the gas is allowed to flow. The pressure gradient in the flowing gas phase is accurately known. The oil in the core is under reduced pressure and the gas at very

* For brevity, relative permeability to gas will hereinafter be referred to as K_g, relative permeability to liquid as K_l, and the equilibrium gas saturation as K_{eq}.

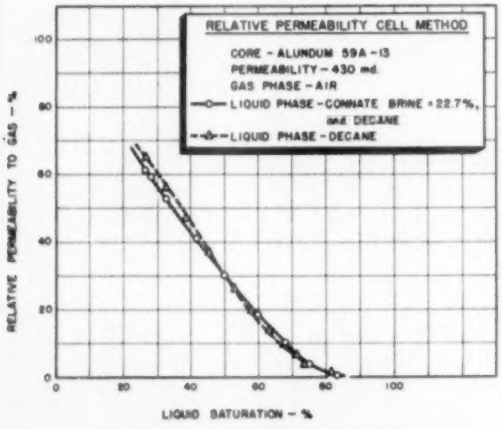

FIG. 3 — RELATIVE PERMEABILITY CELL METHOD.

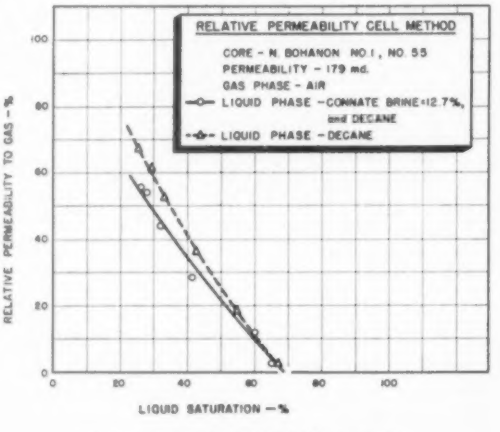

FIG. 4 — RELATIVE PERMEABILITY CELL METHOD.

nearly atmospheric. This cell has also been adapted to three phases, i.e., maintaining interstitial water at a fixed saturation in the core and measuring the permeability to gas at various oil saturations.

APPARATUS AND METHOD

The relative permeability cell shown in Fig. 1 is designed to maintain a pressure difference between fluid phases in the core sample. This cell, together with a gas pump, a manometer, and a flowmeter, makes it possible to measure the effective permeability of a core to gas at each discrete partial oil saturation. The oil saturating the core is held immobile during the measurement of effective permeability to gas.

In the operation of the cell, the core K, completely saturated with oil, is placed in capillary contact with the ceramic disc H which is also completely saturated with oil. The cell is then assembled as shown in Fig. 1 and bolted tightly together. The parts F, F', G, J, L, C, B, D, and A are all made of polished brass or of chromium plated brass. The gas outlet tube C is soldered to disc G and the gas inlet tube B and tube D are soldered to disc J. The ceramic disc H is cemented to tube B and the brass disc J. Between plates G and J and the brass end plates F and F' respectively, are sufficient rubber washers, so that when the end plates are drawn together by bolts, a seal will be provided between L and S at the ends of L and the disc-core assembly G-K-H-J will be compressed sufficiently to establish capillary continuity for the oil between H and K. To facilitate the insertion of the core and discs, a vacuum is applied to A to collapse the rubber sleeve S against L. After the cell has been bolted together, the annular space E between L and S and a few inches of tube A are filled with water. Gas pressure is then applied to force the rubber sleeve against the sides of the core and discs to make a peripheral seal. The ends of brass plate G and the ceramic disc H in contact with the core are grooved to permit a homogeneous distribution of gas as it flows in and out of the core. After the assembly is completed, tube D is filled with oil and is connected to one arm of a flexible U tube mercury manometer so that there is continuity of the saturating oil phase from the top of the mercury through D and H and into the core.

By lowering the mercury in the free arm of the U tube, a reduced pressure is imposed on the oil phase and the oil saturation of the core is reduced. When capillary equilibrium has been reached, gas is allowed to flow in B and out C and hence the effective permeability of the core to gas can be measured. Then the mercury in the free arm is again lowered. This cycle is repeated until the minimum attainable liquid saturation is reached, at which time the core is removed and weighed to determine its liquid saturation. From the calibration of the closed arm of the U tube and the position of the mercury interface in that tube, the saturations of oil at which the permeability is measured can be calculated. The effective permeability of the core to gas at each oil saturation divided by the permeability of the core to gas at zero oil saturation yields the relative permeability to gas at each oil saturation. These data are plotted versus the liquid saturation to give the conventional relative permeability curve.

The difference in level between the

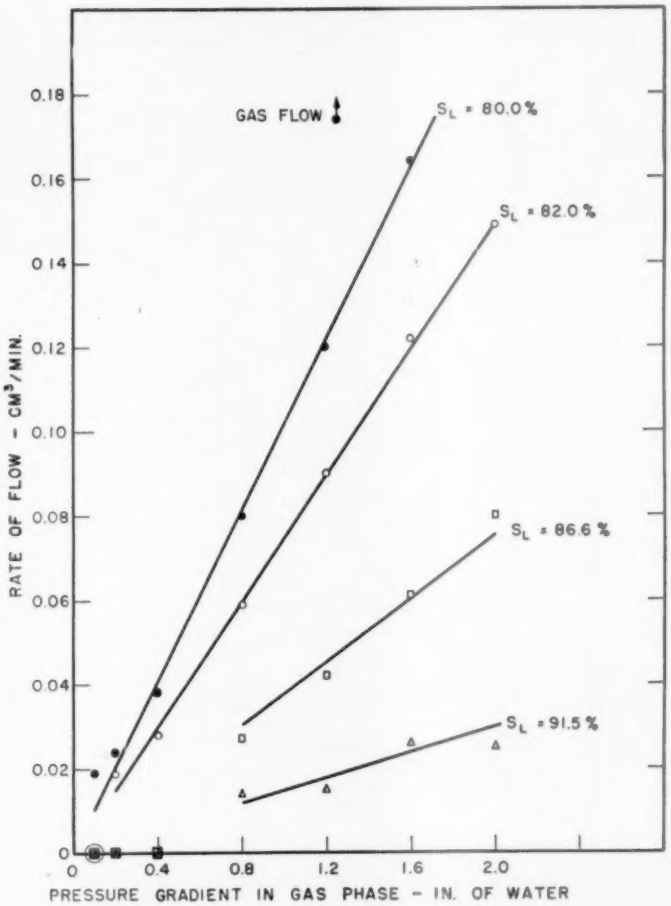

FIG. 5 — RATE OF GAS FLOW AS A FUNCTION OF PRESSURE GRADIENT AND LIQUID SATURATION, ALUNDUM CORE 55-01.

mercury in the two arms of the U tube plus a correction for the liquid above the mercury in the closed arm yields data from which the capillary pressure curve can be obtained.

The maximum reduced pressure permissible on the liquid phase has been found to be about 5 psi. At reduced pressures greater than this value, the continuity of the liquid phase in tube D is interrupted by the formation of gas bubbles which preclude the accurate determination of both the liquid saturation and the capillary pressure. In those cases where capillary pressures in excess of 5 psi are necessary to obtain the requisite liquid saturation slight modifications can be made in the equipment to permit a constant pressure to be applied to the gas phase. This augments the reduced pressure on the liquid phase and the combination of the two suffice to desaturate the core.

After sufficient data have been obtained for the relative permeability to gas curve, the cell is disconnected from the gas flow lines, the tube B is capped, and tube C is connected to a pressure source capable of desaturating the core to its minimum liquid saturation. In this type of experiment either brine, oil, or both can be used as the saturating liquid. If only one liquid is used the initial saturation can be accomplished by the well known evacuation method. If both are used simultaneously and the brine preferentially wets the core, the brine is established in the core by first saturating a dry core with brine and displacing the brine with oil in a restored state displacement cell.[9] This modification requires that disc H in the relative permeability cell be treated with silicones to render it preferentially oil wetted so that the brine will remain in the core and only oil will be drawn out.

The flowmeter used in this research is of rather novel design and is shown in Fig. 2. Air flows in at T_1, up through the burette tube and out at T_2. A film across the burette is formed by lifting B, so that the liquid will rise in C and cover the lower end of the burette. B_1 is then lowered and the film travels up the burette. The time required for the displacement of a given volume is measured with a stopwatch and the volume rate of flow in cc/min is obtained. The film expands at the end of the burette in bulb B, and eventually breaks.

In all gas permeability measurements the phenomenon of gas slippage adjacent to the solid surfaces must not be overlooked. This slippage, frequently called the Klinkenberg effect[10], results in a higher permeability to gas than to liquid under conditions of single phase fluid saturation. The amount of slippage is a function of the ratio of the mean free path of the gas molecules to the radius of the channel through which gas is flowing. Any variations in experimental conditions which change either the mean free path of the gas molecules (such as pressure, temperature, etc.) or which change the average radius of the passages open for the flow of gas will affect the observed permeability to gas. An air permeability at atmospheric temperature and pressure may be greater than a liquid permeability on the same core by a factor of 2. Because of the possibility of changes in the average pore radius of passages available for gas flow as the partial liquid saturation of a porous medium decreases, the Klinkenberg effect should be taken into consideration in the ultimate evaluation of relative permeability to gas

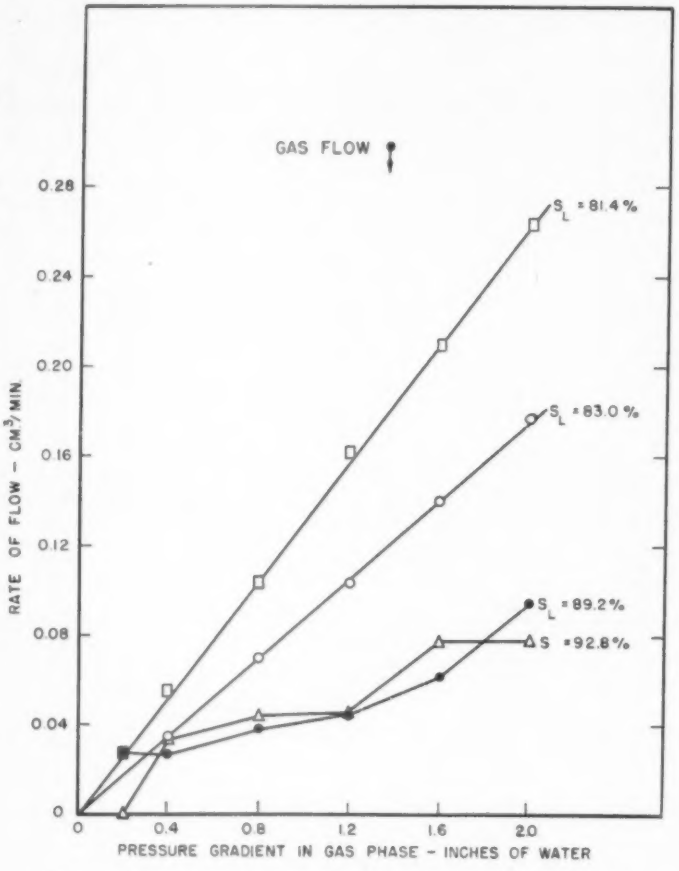

FIG. 6 — RATE OF GAS FLOW AS A FUNCTION OF PRESSURE GRADIENT AND LIQUID SATURATION, ALUNDUM CORE 55-01.

data. According to Rose[11] this effect appears to be small.

RESULTS AND DISCUSSION

Quite early in the experimental program it became apparent that natural cores failed to meet the requirements as to uniformity, permeability range, similarity in textural properties, and durability which would be required of cores subjected to repeated handling of the sort which might be encountered in the development and testing of apparatus. Much of the work, therefore, has been done using 12 alundum cylinders 1-in. x 1-in. and varying in permeability from 30 to 3300 md. N-decane was used as the saturating liquid phase.

From time to time as the progress of the program warranted, runs were made on natural cores. Since considerably more data have been obtained than are shown in this paper, an attempt has been made to show data which are representative of the whole for illustrative purposes. A comparison between a decane-air system and a connate water-decane-air system using an alundum core is shown in Fig. 3 and a similar comparison using a natural core is shown in Fig. 4.

For both synthetic core material and natural reservoir rock, it is observed that there is good agreement between the results of two phase (gas-oil system) and those of three phase (gas-oil-connate water) systems. The agreement is slightly better in the region of the equilibrium gas saturation, i.e., at that saturation of liquid at which gas first flows. These figures show that the relative permeability to gas is determined by the total liquid saturation and is independent of the presence of water as a co-saturant.

Because of its importance in reservoir engineering calculations and reservoir exploitation, the equilibrium gas saturation is of particular interest. Hassler, Brunner, and Deahl[12] have indicated that the equilibrium gas saturation can occur over a range of several per cent depending mainly upon the extent of any "trap hysteresis" effect. They say, however, that one definite *highest* value of equilibrium gas saturation can be determined by experimental means. This value results from a continual desaturation process until the pressure that is just sufficient to start the flow of gas through the porous medium reaches zero. In other words no liquid has to be displaced or moved aside in order for gas flow to be accomplished. That value of equilibrium gas saturation is probably more significant than any other in regard to the production of oil from a dissolved gas-drive reservoir, and is therefore the value sought in most engineering uses. Some of the early work with the relative permeability cell method had indicated that Darcy's law might not be applicable in the region of the equilibrium gas saturation. Other investigators, using different methods, have exhibited data which indicate that the relative permeability of a core to gas is a function of the rate of flow.[8,7] In order to clarify this, two tests were made using an alundum core having a dry air permeability of 177 md. In the first test the core was set up in the relative permeability to gas cell so that the gas flowed through the core from bottom to top. At discrete liquid saturations a pressure difference was applied in successively increasing steps and the resulting gas flow rate was measured. The data are presented in Fig. 5.

At the higher liquid saturations, no gas flow is obtained for the lower pressure differences. However, once a pressure gradient giving flow has been reached, the rate of flow is more or less

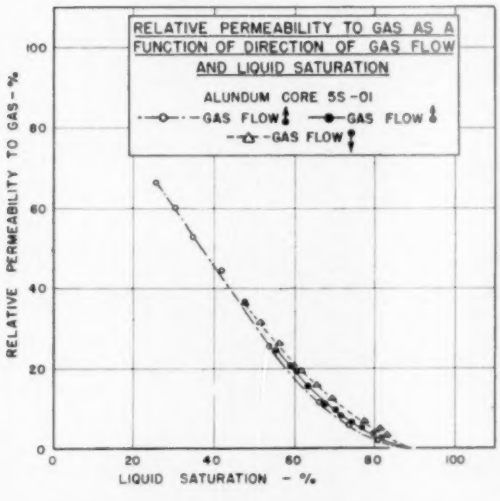

FIG. 7 — RELATIVE PERMEABILITY TO GAS AS A FUNCTION OF DIRECTION OF GAS FLOW AND LIQUID SATURATION.

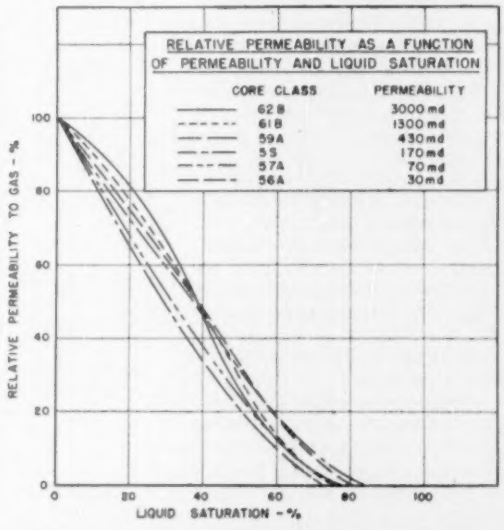

FIG. 8 — RELATIVE PERMEABILITY AS A FUNCTION OF PERMEABILITY AND LIQUID SATURATION.

linear with the pressure gradient. The line segments indicate the range over which flow was obtained. In going from 86.6 per cent to 82 per cent liquid saturation there is a decided improvement in the quality of the data and at the latter saturation gas flow was obtained at the lowest pressure gradient applied. This test therefore indicates that the maximum value of the equilibrium gas saturation lies between 82.0 per cent and 86.6 per cent.

In the second test, the core was set up in the same cell and the gas flow through the core was reversed so that it flowed through the core from top to bottom. The data for this test are shown in Fig. 6. Here, although there is gas flow for all applied pressure gradients at the higher liquid saturations, the data are quite irregular and Darcy's law does not appear to be valid. As in the first test, though, in passing from 89.2 per cent to 83.0 per cent saturation, there is again the distinct improvement in the data and at the latter saturation Darcy's law is valid. Here the maximum value of the equilibrium gas saturation is fixed between the limits of 83.0 per cent and 89.2 per cent.

When the first and second tests on this core are considered together the equilibrium gas saturation is bracketed between the values of 83.0 and 86.6 per cent. The relative permeability to gas curves from these two tests are shown in Fig. 7. The curves extrapolate to an equilibrium gas saturation of 88.0 per cent. The fact that this extrapolated value is slightly higher than the previously indicated maximum perhaps is explained by the fact that in the test cell approximately 50 per cent of one end of the core is in contact with the porous plate so that at liquid saturations very near the equilibrium gas saturation some passages, although filled with gas, are not available for its flow because they terminate at the porous plate. As the liquid saturation decreases the interconnection between passages increases and all become available for flow.

A review of the data of Figs. 3, 4, 5 and 7 shows that although there are deviations among sets at the lower liquid saturations, they converge in the region of the equilibrium gas saturation so that its determination is rather precise. The pressure gradients in the gas phase in these tests have been varied from 0.2 in. to 2.0 in. water. This is considerably less than has been used by other investigators[1,3,4,6,6,7] some of whom report a variation in relative permeability with rate of flow.[6,7] The data of Figs. 5 and 6 do not support this conclusion and the numerous other data obtained show that over this tenfold change in pressure gradient the relative permeability to gas is independent of rate of flow. The use of pressure gradients greatly in excess of those found in the reservoir can easily lead to experimental difficulties, such as displacement effects, which obscure the results. It appears that under the conditions of these experiments and in the reservoir the relative permeability to gas is independent of the rate of flow.

Some work was done to determine whether variations in the specific permeabilities of different cores would be reflected in the appearance of the relative permeability to gas curves of those cores.

For each of the six pairs of alundum cores an average relative permeability to gas curve was obtained in the following manner: Using the curves resulting from the two and three-phase experiments where decane was the displaced liquid phase, a mean liquid saturation value for a given relative permeability value was calculated and plotted against that relative permeability. Enough points were chosen for each pair of cores so that a complete curve resulted. The curves, six in number, were then plotted as in Fig. 8.

It appears that, at least for these alundum cores, there may be a correlation between permeability and relative permeability. At lower liquid saturations there is, without variation, a shifting to the right of the mean relative permeability curve for each step in increasing permeability. At liquid saturations above 40 per cent the trend is somewhat reversed, the shift being to the left with increasing permeabili-

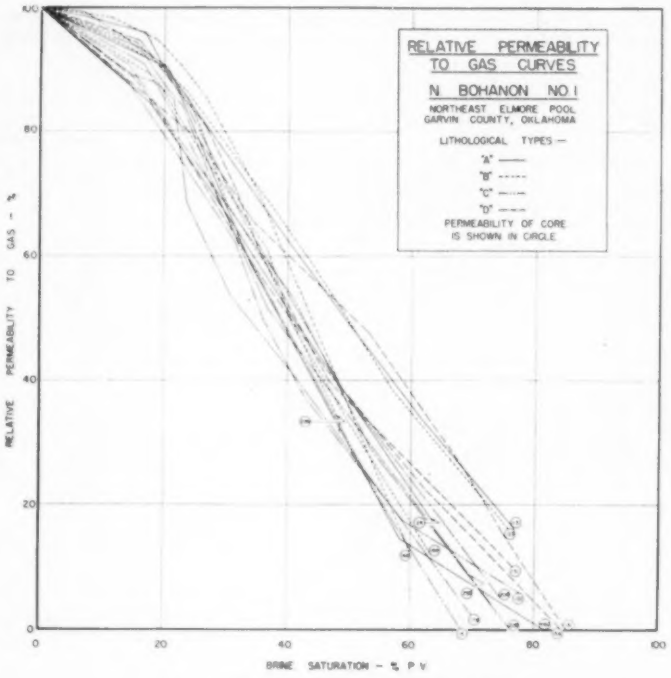

FIG. 9 — RELATIVE PERMEABILITY TO GAS CURVES.

ties. The disposition of the curves in this region, however, does not lend itself to such a generalization as at the lower liquid saturations, since exceptions occur here.

This apparent correlation should not be emphasized since it might be due mainly to the nature of the alundum cores. These particular cores all consist of the same two grain sizes, in varying percentages, and are entirely homogeneous. That the correlation does not exist for natural specimens can be seen from Fig. 9. Here the relative permeability curves are shown for 16 cores recovered from the N. Bohanon No. 1 well, Garvin County, Oklahoma. The figures in the circles are the dry air permeabilities. There is no apparent correlation between permeability and relative permeability. If a correlation exists it is masked by petrofabric variables.

As a matter of fact, the only variables encountered in the course of the laboratory experiments which have an appreciable effect on the relative permeability have been grain size distribution, rock surface characteristics, etc. This is brought out in Fig. 9 where cores of practically the same permeability have widely divergent relative permeability to gas curves. Additional data to illustrate this are shown in Fig. 10 where relative permeability to gas curves are presented for an alundum core, an N. Bohanon No. 1 core and a Nichols Buff sandstone core. Here it is seen that the equilibrium gas saturation for the Bohanon core is 69 per cent, whereas for the other two it is 88 per cent. The curves for the Nichols Buff core and the alundum core are practically identical above a saturation of 60 per cent. Below that saturation they diverge and the curve for the alundum core crosses the Bohanon curve at about 25 per cent saturation.

In the section describing the relative permeability cell it was mentioned that a capillary pressure curve was obtained simultaneously with the relative permeability to gas curve. Since the equipment and procedure are different from those employed with the displacement cell a comparison of the capillary pressure curves obtained by the two methods is in order and is shown for two representative cores in Fig. 11. Also shown is the curve obtained with one of the cores when connate water was present in the core. It will be observed that the agreement between the curves is sufficient to justify the statement that the two methods give the same results.

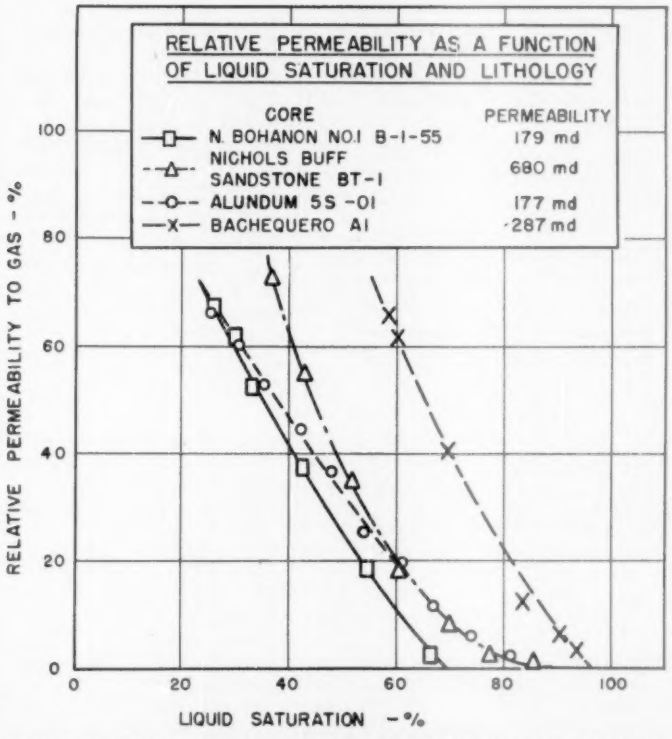

FIG. 10 — RELATIVE PERMEABILITY AS A FUNCTION OF LIQUID SATURATION AND LITHOLOGY.

CONCLUSIONS

From the foregoing discussion, the following conclusions may be drawn:

1. The data obtained by the method described above have a high degree of internal consistency and are reproducible from one test to another.
2. Rate of gas flow has no effect on relative permeability to gas as obtained by this stationary liquid method.
3. No definite correlation has been found between permeability and relative permeability to gas for the systems studied.
4. No definite correlation has been found between petrofabric factors and relative permeability to gas for the systems studied.
5. The capillary pressure curves obtained in the relative permeability cell agree with those obtained in a conventional displacement cell.

NOTE REGARDING USE OF DATA

In view of the fact that variations of relative permeability appear to exist within a single reservoir (see Fig. 9) it becomes necessary to deal with weighted average relative permeability values in the consideration of reservoir engineering problems. For the case of parallel non-connecting strata open to the same well, this averaging process would be as follows:

$$(K_a)_{ave.} = \frac{\sum_{1}^{n} k_a (K_a)_a x_a}{\sum_{1}^{n} k_a x_a}$$

in which k_a is the specific permeability of a uniform stratum x_a thick.

Other more complex systems would require more elaborate means of averaging but would follow the same general principle indicated above.

ACKNOWLEDGMENT

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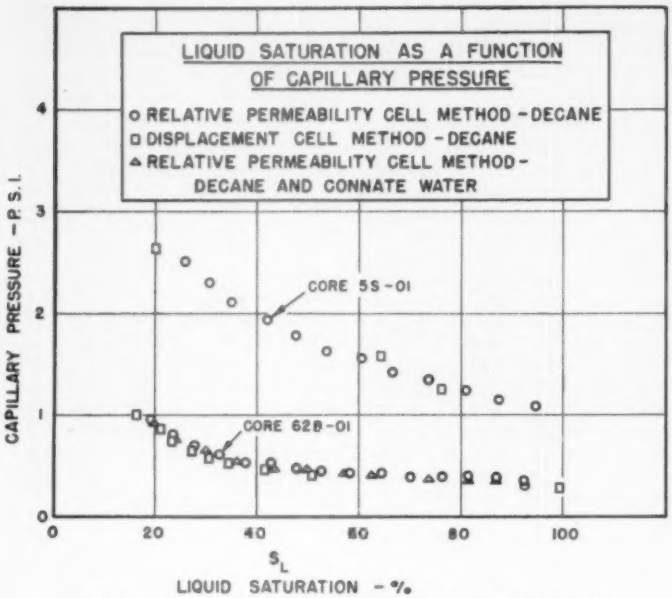

FIG. 11 — LIQUID SATURATION AS A FUNCTION OF CAPILLARY PRESSURE.

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T.P. 2777

DETERMINING FRICTION FACTORS FOR MEASURING PRODUCTIVITY OF GAS WELLS

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ABSTRACT

The theoretical background for calculating friction factors for flow in gas wells by two methods is presented. The first method, requiring pressures, temperatures and specific volumes of the flowing fluids at various depths in the well bore, shows how the mechanical-energy-balance equation for vertical flow may be graphically integrated over the actual path of the expansion of the fluid in the well. Thus, assumptions regarding the effective temperature and effective compressibility of the fluid in the well are avoided. The second method presents an equation derived on a basis of the assumptions that both the temperature and the compressibility are fixed at constant effective values throughout the flowing column of gas. The second method provides a convenient and practical means of calculating friction factors for gas wells and lends itself readily to the problem of calculating subsurface pressures in a flowing gas well. The application of both methods to actual test data taken on a flowing gas well is illustrated in the paper.

INTRODUCTION

As friction factors for the producing strings of flowing gas wells cannot be measured directly and must be calculated from flow-test data, study of the methods of arriving at friction factors is a necessary adjunct to understanding the characteristics of flow in gas wells. There are two methods of calculating friction factors for gas wells; they differ from one another mainly in the treatment of the path of expansion of the fluid in the well. In the flowing well, the energy consumed in lifting the fluid from the bottom to the top of the well, overcoming the friction between the moving fluid and the pipe walls, and increasing the velocity of the fluid as it flows up the producing string is supplied by expansion of the flowing fluid. The available energy is determined by the expansion of the fluid that follows a path determined by conditions of temperature, compressibility and phase changes of the fluid during the expansion. A means of evaluating the available energy in a flowing gas well and determining the proportion of the available energy used in lifting the gas, overcoming friction, and increasing the velocity of flow is developed in this report. Knowing how much energy is consumed in overcoming friction makes it possible to calculate friction factors for given flow rates in given sizes of pipes in wells.

Friction coefficients, as used in this report, are dimensionless proportionality multipliers used in the flow equations to satisfy the equality between the terms of the equation. The square root of the reciprocal of the friction coefficient is termed the friction factor.

It has been known for many years that friction factors may be computed directly from mathematical formulas based on certain assumptions regarding the temperature and compressibility of the moving fluid in a well. A general equation is presented in this report without assumptions for vertical flow of fluids and a conventional-type equation is derived on the basis of assumptions that fix the temperature and compressibility at constant values. Accurate pressures at the sand faces in wells are required in the method of determining the productivity of gas wells, as outlined by Rawlins and Schellhardt[1] in Bureau of Mines Monograph 7. Where measurements are not made with subsurface-pressure gauges or static gas columns are unavailable, flowing pressures customarily are calculated at the sand face in the well by the use of the well-known Weymouth formula[1]. Natural gas engineers have realized that errors introduced by the use of friction factors as given by the Weymouth formula are relatively unimportant in testing low-capacity gas wells; they also know that such factors are important considerations in testing large-capacity gas wells. Accordingly, present research on the productivity of gas wells at the Petroleum Experiment Station of the Bureau of Mines, Bartlesville, Okla., is being directed toward measurement of the pressure loss due to friction in flowing gas wells.

It is beyond the scope of this report to show how friction factors vary with rate of flow and in pipes of different diameters, as it is intended only to develop and illustrate the use of mathematical expressions for calculating friction factors from flow-test data. The equations presented apply only to turbulent flow in circular pipes.

ENERGY RELATIONS FOR FLOW OF FLUIDS[2]

The concept of conservation of energy is usually the basis of any study of fluid flow through vertical pipes as in gas wells, horizontal pipe lines, or orifices. In deriving equations, the following symbols are used:

[1] References given at end of the paper.

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[2] The explanation, in this report, of energy relations for fluid flow was taken from a discussion of flow of fluids by Cattell.[3]

A = cross-sectional area of the flow channel, sq ft
U = mean linear velocity of flow parallel to the axis of channel at a given cross section, ft per sec
g = acceleration of gravity, ft per sec per sec
E = total internal energy or intrinsic energy associated with one pound of fluid, ft-lb
p = pressure, lb per sq ft abs
P = pressure, lb per sq in. abs (psia)
v = specific volume of fluid, cu ft per lb
L = distance of a cross section above an assumed datum plane, ft
q = heat, in equivalent ft-lb, imparted to 1 lb of fluid from outside the fluid body
F = mechanical energy, ft-lb per lb of fluid, transformed into heat by frictional resistances.

Subscripts 1 and 2 applied to any of the symbols denote conditions at an upstream cross section A_1 and a downstream cross section A_2; respectively. In the example considered in this report, the upstream cross section A_1 is lower in elevation than the downstream cross section A_2.

Consider a fluid flowing upward from section A_1 to section A_2 through a circular vertical pipe in which A_1 equals A_2 in area. As the fluid under consideration is elastic, it fills the pipe completely, and no external forces except gravity act upon it between the two sections.

In considering a hypothetical well the following assumptions are made:

1. The fluid is homogeneous.
2. The flow is steady with respect to time; that is, in a unit of time the same weight of fluid flows through every cross section.
3. The fluid flows with mean linear velocity U_1 parallel to the axis of the pipe and at right angles to the plane of the cross section, A_1. The mean velocity may be defined as

$$U = \frac{Nv}{A}$$

where

N = weight rate of flow, lb per sec
v = specific volume of the fluid at the point under consideration, cu ft per lb
A = area of cross section under consideration, sq ft

As the flow is considered steady, 1 lb of the fluid passes through sections A_1 and A_2 in the same interval of time. When 1 lb of fluid passes the lower section A_1 it carries with it the following energy:

E_1, its internal energy, resulting from its temperature and the position of its molecules,

$\frac{U_1^2}{2g}$, its kinetic energy, attributable to its upward velocity,

p_1v_1, which represents the mechanical work performed in forcing the pound of fluid across section A_1,

L_1, which is the potential energy (referred to the assumed datum plane) of the pound of fluid resulting from the action of gravity upon it.

Applying terms used in hydraulics, $\frac{U_1^2}{2g}$, p_1v_1 and L_1 may be called, respectively, the velocity head, pressure head, and potential head of 1 lb of fluid at section A_1.

Under the conditions stipulated, the pound of fluid receives no mechanical energy from external sources while passing from A_1 to A_2, but it may receive heat q from sources outside the fluid. If the fluid loses heat, q has a negative value.

At Section A_2, 1 lb of fluid has the internal energy E_2, the velocity head $\frac{U_2^2}{2g}$, the pressure head p_2v_2 and the potential head L_2.

Balancing all forms of energy and expressing quantities of heat in units of equivalent work, it is apparent that:

The internal energy, velocity head, pressure head, and potential head of 1 lb of fluid at section A_1, plus the heat per lb of fluid imparted from external sources to the fluid between sections A_1 and A_2, equals the internal energy, velocity head, perssure head, and potential head of 1 lb of fluid at section A_2, or,

$$E_1 + \frac{U_1^2}{2g} + p_1v_1 + L_1 + q = E_2 + \frac{U_2^2}{2g} + p_2v_2 + L_2 \quad . \quad (1)$$

Between sections A_1 and A_2 each pound of fluid does the mechanical work $\int_{v_1}^{v_2} pdv$ upon the surrounding fluid; thus each pound of fluid must receive that amount of work from the rest of the fluid between the two sections. Such work can be done only by converting heat energy of the fluid into mechanical energy. As the work and heat must be equivalent, $\int_{v_1}^{v_2} pdv$ is the measure per pound of flowing fluid, not only of the work received but also of the heat (expressed in equivalent work units) that was transformed into that work. It may, therefore, be considered that each pound of fluid does the work $\int_{v_1}^{v_2} pdv$ upon itself at the expense of its own heat energy.

For each pound of fluid flowing from section A_1 to section A_2 the mechanical work F done against frictional resistance is converted into heat F (expressed in work units) absorbed by the fluid.

With these conceptions, and measuring heat in equivalent work units, a balance of heat (or nonmechanical) energy may be expressed as follows:

The internal energy of 1 lb of the fluid at section A_1, minus the heat energy per pound of fluid transformed into mechanical work by expansion of the fluid between the two sections, plus the heat per pound of fluid into which mechanical work is transformed in overcoming frictional resistance between the two sections, plus the heat per pound of fluid imparted from external sources to the fluid between the two sections, is equal to the internal energy of 1 lb of fluid at section A_2, or

$$E_1 - \int_{v_1}^{v_2} pdv + F + q = E_2 \quad . \quad . \quad . \quad . \quad (2)$$

Subtraction of equation (2) from equation (1) gives equation (3)[1]

[1] Equation (3) may be developed also by balancing mechanical energy. The velocity head, pressure head, and potential head of 1 pound of fluid at section A_1, plus the work per pound of fluid (derived from heat energy) done upon the fluid between the two sections, minus the mechanical energy per pound of fluid converted into heat by frictional resistances between the two sections, is equal to the velocity head, pressure head, and potential head of 1 pound of fluid at section A_2.

$$\frac{U_1^2}{2g} + p_1v_1 + L_a + \int_{v_1}^{v_2} pdv - F = \frac{U_2^2}{2g} + p_2v_2 + L_a \quad . \quad (3)$$

Equation (3) may be written in the form:

$$p_1v_1 + \int_{v_1}^{v_2} pdv - p_2v_2 = (L_a - L_1) + \frac{U_2^2 - U_1^2}{2g} + F \quad . \quad (4)$$

Equation (4) may be considered a general one for the flow of fluids in pipes.

EQUATIONS FOR FLOW OF FLUIDS IN VERTICAL PIPES

Method I (graphic integration)

The application of equation (4) to the evaluation of friction factors for gas wells requires further treatment of term F or the mechanical energy per pound of fluid transformed into heat by frictional resistance. The work done in overcoming frictional resistance through distance dL equals frictional resistance times the distance through which the resistance is overcome. For turbulent flow the frictional resistance is proportional to the surface in contact with the fluid, to the density of the fluid, and approximately proportional to the square of the velocity. If the resistance is proportional to the square of the velocity it is also proportional to the first power of the kinetic energy $\frac{U^2}{2g}$ of 1 lb of fluid. Expressed by symbols, the frictional resistance is proportional to:

$$(dL) \quad (Per) \quad \left(\frac{U^2}{2g}\right) \quad (S)$$

where

dL = length of pipe, ft
Per = perimeter of pipe, ft
U = velocity, ft per sec
S = density, lb per cu ft

or

$$\text{frictional resistance} = (f)\ (dL)\ (Per)\ \left(\frac{U^2}{2g}\right)(S) \quad . \quad (5)$$

The term f then becomes a proportionality factor to satisfy the equality; it is commonly called the coefficient of friction.

Multiplying the frictional resistance as expressed in equation (5) by the length of pipe dL to obtain the work in overcoming the resistance and dividing by the pounds of fluid contained in the length of pipe dL, the work expended per pound of fluid in overcoming frictional resistance becomes:

$$dF = \frac{(f)\ (dL)\ (Per)\left(\frac{U^2}{2g}\right)(S)\ (dL)}{(A)\ (dL)\ (S)} \quad . \quad (6)$$

where

A = cross-sectional area, sq ft.

For a circular pipe the perimeter divided by the area equals $\frac{4}{D}$ where D is the internal diameter in ft. Equation (6) becomes:

$$dF = \frac{4f\ U^2\ dL}{2gD} \quad . \quad (7)$$

or for a finite length of pipe

$$F = \frac{4f}{2gD}\int_{L_a}^{L_0} U^2\ dL \quad . \quad (8)$$

substituting the value of the term F given in equation (8) into equation (4)

$$p_1v_1 + \int_{v_1}^{v_2} pdv - p_2v_2 = (L_a - L_1) + \frac{U_2^2 - U_1^2}{2g} + \frac{4f}{2gD}\int_{L_1}^{L_2} U^2\ dL \quad . \quad (9)$$

The expression at the left of the equality sign (as may be shown analytically or graphically), equals

$$-\int_{p_1}^{p_2} vdp$$

or

$$\int_{p_2}^{p_1} vdp.$$

If the pressures are expressed in psi instead of lb per sq ft, the expression equals

$$144\int_{P_2}^{P_1} vdP.$$

As equation (9) contains a velocity term U which is not commonly used in the gas industry, velocity in ft per sec may be converted to cu ft per 24 hours and specific volume expressed in cu ft per lb by:

$$U = \frac{Nv}{A}$$

where

U = velocity, ft per sec
N = rate of flow of fluid, lb per sec
v = specific volume, cu ft per lb
A = cross-sectional area of pipe, sq ft.

When the volume rate of flow is measured in cu ft of gas per 24 hours, the term N becomes:

$$N = \frac{QG}{86{,}400 \times 13.364}$$

where

Q = volume rate of flow, cu ft per 24 hours (absolute pressure base = 14.4 psi and temperature base = 60°F)
G = specific gravity of fluid, air = 1.0
86,400 = number of seconds in 24 hours
13.364 = volume of one pound of dry air at an absolute pressure of 14.4 psi and at a temperature of 60°F, cu ft.

Then the velocity term U becomes:

$$U = \frac{QGv}{1{,}154{,}600\ A} \quad \text{or}$$

$$U^2 = \frac{Q^2G^2v^2}{1.3331 \times 10^{12}\ A^2} \quad .$$

By making the indicated substitutions and changing the subscripts 1 and 2 so that they indicate conditions at a depth s and at the wellhead (L = 0) respectively, taking the value of g, the acceleration of gravity, to be 32.17 ft per sec per sec, and changing elevations to depths, equation (9) becomes:

$$144\int_{P_w}^{P_s} vdP = L_a + \frac{Q^2G^2(v_w^2 - v_s^2)}{85.772 \times 10^{12}\ A^2} + \frac{fQ^2G^2}{21.443 \times 10^{12}\ DA^2} \int_0^{fL} v^2 dL \quad . \quad (10)$$

Changing A which is in units of sq ft into terms of inside pipe diameter, in in., and D, in ft, to in., equation (10) becomes:

$$144\int_{P_w}^{P_s} vdP = L_s + \frac{Q^2G^2(v_w^2 - v_s^2)}{2.5515 \times 10^{17}\ d^5} + \frac{fQ^2G^2}{53.157 \times 10^{17}\ d^5} \int_0^L v^2 dL \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where

- P = pressure, psia
- v = specific volume, cu ft per lb
- L_s = energy required to lift 1 lb of the fluid from depth L in the well, ft-lb (as 1 lb of fluid is under consideration L_s is numerically equal to L)
- L = depth of flowing column of fluid, ft
- Q = volume rate of flow, cu ft per 24 hours (absolute pressure base = 14.4 psi and temperature base = 60°F)
- G = specific gravity of fluid, air = 1.0
- d = internal pipe diameter, in.
- f = friction coefficient, dimensionless

The subscripts s and w refer to conditions at depth L and at the wellhead respectively.

As equation (11) does not contain assumptions which define the path of the expansion of the fluid, it may be considered general for the flow of fluids in wells.

Method II (mathematical integration)

Starting with equation (9)

$$p_1v_1 + \int_{v_1}^{v_2} pdv - p_2v_2 = (L_2 - L_1) + \frac{U_2^2 - U_1^2}{2g} + \frac{4f}{2gD}\int_{L_1}^{L_2} U^2 dL \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and making the following assumptions:

1. The flow of fluid in a gas well can be considered to be isothermal at an "effective" temperature.
2. The deviation of the fluid from the ideal gas laws throughout the flow string of the well can be considered constant and can be expressed as an "effective" compressibility factor.

Then the following relationship exists:

$$p_1v_1 = p_2v_2 = ZTb$$

where

- Z = effective compressibility factor, dimensionless
- T = effective absolute temperature, °F + 459.6
- b = gas constant in appropriate units for 1 lb of gas.

In accordance with the assumptions, equation (9) becomes:

$$\int_{v_1}^{v_2} pdv = (L_2 - L_1) + \frac{U_2^2 - U_1^2}{2g} + \frac{4f}{2gD}\int_{L_1}^{L_2} U^2 dL \quad . \quad (12)$$

or in differential form[4] it is:

$$pdv = dL + \frac{UdU}{g} + \frac{4f}{2gD} U^2 dL \quad . \quad . \quad . \quad . \quad . \quad (13)$$

As shown in a previous section of this report, velocity equals rate of flow (weight basis) times specific volume divided by the cross-sectional area.

$$U = \frac{Nv}{A}, \text{ and } dU = \frac{Ndv}{A}.$$

Also, pressure may be expressed in terms of specific volume by the relationship:

$$pv = ZTb,\ p = \frac{ZTb}{v}$$

Substituting $\frac{Nv}{A}$, $\frac{Ndv}{A}$, and $\frac{ZTb}{v}$ for U, dU, and p, respectively, in equation (13),

$$ZTb\frac{dv}{v} = dL + \frac{N^2}{gA^2} vdv + \frac{4fN^2}{2gDA^2} v^2 dL \quad . \quad . \quad (14)$$

Rearranging and collecting terms,

$$dL = ZTb\frac{dv}{v\left(\frac{4fN^2}{2gDA^2}v^2 + 1\right)} - \frac{N^2}{gA^2}\frac{vdv}{\left(\frac{4fN^2}{2gDA^2}v^2 + 1\right)} \quad (15)$$

Integrating between the limits, $L = 0$ and $v = v_1$ at the lower, or upstream, end of the length of flow string under consideration and $L = L$ and $v = v_2$ at the wellhead, the result is,

$$L\Big]_0^L = ZTb\left[\frac{1}{2}\log\frac{v^2}{\frac{4fN^2}{2gDA^2}v^2 + 1}\right]_{v_1}^{v_2} - \frac{N^2}{gA^2}\left[\frac{1}{2\left(\frac{4fN^2}{2gDA^2}\right)}\log\left(v^2 + \frac{1}{\left(\frac{4fN^2}{2gDA^2}\right)}\right)\right]_{v_1}^{v_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

or

$$e^{\frac{2L}{ZTb}} = \left(\frac{v_2^2}{v_1^2}\right)\left[\frac{\left(\frac{4fN^2}{2gDA^2}\right)v_2^2 + 1}{\left(\frac{4fN^2}{2gDA^2}\right)v_2^2 + 1}\right]\left(1 + \frac{D}{2fZTb}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

substituting pressure for specific volume according to the following relationships:

$$p_1v_1 = p_2v_2 = ZbT$$

$$v_1^2 = \frac{Z^2b^2T^2}{p_1^2},\ v_2^2 = \frac{Z^2b^2T^2}{p_2^2}$$

equation (17) becomes:

$$e^{\frac{2L}{ZTb}} = \left(\frac{p_1^2}{p_2^2}\right)\left[\frac{p_2^2\left(\frac{2fN^2Z^2T^2b^2}{gDA^2} + p_1^2\right)}{p_1^2\left(\frac{2fN^2Z^2T^2b^2}{gDA^2} + p_2^2\right)}\right]\left(1 + \frac{D}{2fZTb}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

where

- e = natural logarithm base = 2.71828+
- L = length of pipe, ft
- Z = effective compressibility factor, dimensionless

[4] Using the transformation of the terms to the left of the equality sign in equation (9), which is explained in the previous section of the text, an alternate differential form is obtained.

$$vdp + dL + \frac{UdU}{g} + \frac{4f}{2gD} U^2 dL = 0 \quad . \quad . \quad . \quad (13a)$$

The solution of equation (13a) yields equation (18). Identical solutions for equations (13) and (13a) are made possible by the given assumptions regarding temperature and compressibility.

T = effective absolute temperature, °F + 459.6

b = gas constant = $\frac{1545.4}{M}$, cu ft, lb per sq ft, per degree F abs per lb, M = molecular weight

p_1 = pressure at lower, or upstream, end of section under consideration, lb per sq ft abs

p_2 = pressure at wellhead, lb per sq ft abs

f = friction coefficient, dimensionless

N = rate of flow of gas, lb per sec

g = acceleration due to gravity, ft per sec per sec

D = inside pipe diameter, ft

A = cross-sectional area of pipe, sq ft.

Further simplification of equation (18)[5] may be accomplished by considering the exponent $\left(1 + \frac{D}{2fZTb}\right)$ and by substituting the values of the symbols shown later under Method I of this report. The inside diameter of the flow string was 5.012 in. and the average value of the friction coefficient was 0.003664 (see Table II) for the three depths considered. The effective compressibility factor may be assumed to be 0.964 and the effective temperature to be 540.9°F abs. The value of b, the gas constant for 1 lb of gas, may be computed from its specific gravity (0.708) by:

$$b = \frac{53.327}{G}$$

where 53.327 is the gas constant for 1 lb of dry air, and G is the specific gravity of the gas referred to air.

The value of the exponent $\left(1 + \frac{D}{2fZTb}\right)$ becomes

$$1 + \frac{\frac{5.012}{12}}{2 \times .003664 \times .964 \times 540.9 \times \frac{53.327}{.708}} = 1.00145$$

The exponent 1.00145 means that the quantity in brackets, equation (18), is to be multiplied by its 690th root. Although the exact implications of the fractional part of the exponent are difficult to describe for all gas-well conditions, it is believed that the fractional portion of the exponent can be neglected for rates of flow used in testing gas wells. Also, the fractional portion of the exponent is derived from the kinetic energy term of equation (14) and usually is neglected in horizontal pipe line formulas.

Assuming that the exponent is unity, equation (18) becomes:

$$p_1^2 - e^{\frac{2L}{ZTb}} p_2^2 = \left(\frac{2fN^2Z^2T^2b^2}{gDA^2}\right)\left(e^{\frac{2L}{ZTb}} - 1\right) \quad . \quad (19)$$

Rearranging and dividing by p_1^2

$$\frac{NZTb}{p_1} = Nv_1 = A\left[\frac{(Dg)}{(2fp_1^2)} \frac{(p_1^2 - e^{\frac{2L}{ZTb}} p_2^2)}{\left(e^{\frac{2L}{ZTb}} - 1\right)}\right]^{1/2} \quad (20)$$

where Nv_1 = volume rate of flow at a pressure of p_1 and a temperature of T, cu ft per sec.

[5] This simplification of equation (18) was suggested by M. H. Cullender of the Phillips Petroleum Co., Bartlesville, Okla.

Equation (20) may be simplified further for use in the natural-gas industry by converting the variables to terms that are easily measured. It is customary to express the quantity that will flow in a well through a flow string of given dimensions, under various pressure conditions, in terms of cu ft per 24 hours at specific pressure and temperature bases. To convert volume Nv_1 in equation (20) from cu ft per second at temperature T and pressure p_1 to cu ft per 24 hours Q at a base temperature of T_b and base pressure of P_b it is necessary to multiply by

$$24 \times 3600 \frac{P_1T_b}{P_bZT}$$

Also, it is customary to express pressure in units of lb per sq in. abs (psia), pipe diameter in in., and area in sq ft in terms of diameter in in. Conversions in these units are obtained by substituting in equation (20) the following:

$p = 144\ P$, where p is in lb per sq ft and P in psia,

$D = \frac{d}{12}$, where D is in ft and d in in., and

$A = \frac{\pi d^2}{4 \times 144}$

Also, gas constant b was shown to equal $\frac{53.327}{G}$. Substituting this quantity for b in the exponent of e, the exponent becomes $0.037504 \frac{GL}{TZ}$

It is convenient to use the symbol s for the exponent of e in equation (20).

Equation (20) now becomes:

$$Q = 24 \times 3600 \frac{P_1T_b}{P_bZT} \times \frac{\pi d^2}{4 \times 144} \times \left[\frac{(32.17)}{(2)} \frac{(d)}{(P_1^2)} \frac{(f)}{\left(\frac{(P_1^2 - e^s P_2^2)}{e^s - 1}\right)}\right]^{1/2} \quad (21)$$

or

$$Q = 545.58 \frac{T_b}{P_b}\left(\frac{1}{ZT}\right)\sqrt{\frac{1}{f}}\sqrt{d^5\left(\frac{P_1^2 - e^s P_2^2}{e^s - 1}\right)} \quad (22)$$

If $T_b = 60 + 459.6 = 519.6$ °F abs and $P_b = 14.4$ psia equation (22) becomes

$$Q = 19{,}686\left(\frac{1}{ZT}\right)\sqrt{\frac{1}{f}}\sqrt{d^5\left(\frac{P_1^2 - e^s P_2^2}{e^s - 1}\right)} \quad (23)$$

where

Q = volume rate of flow, cu ft per 24 hours (absolute pressure base = 14.4 psi and temperature base = 60°F)

Z = effective compressibility of gas, dimensionless (see text for explanation)

T = effective temperature, °F abs (see text for explanation)

f = friction coefficient, dimensionless

$\sqrt{\frac{1}{f}}$ = friction factor, dimensionless

d = inside diameter of pipe, in.

P_s = subsurface pressure at depth L in the well, psia
P_w = wellhead pressure, psia
e = natural logarithm base = 2.71828+
s = exponent of e in equations (22) and (23) = $0.037504 \frac{GL}{TZ}$
G = specific gravity of gas, air = 1.0
L = length of pipe, ft.

If the quantity to the right of the equality sign in equation (23) is multiplied by and at the same time divided by the square root of s, the terms may be rearranged into the following equation:

$$Q = 101{,}650 \sqrt{\frac{d^5}{GZT}} \sqrt{\frac{1}{f}} \sqrt{\left(\frac{P_s^2 - e^s P_w^2}{L}\right)\left(\frac{s}{e^s - 1}\right)} \quad \ldots\ldots (24)$$

Equations (23) and (24) are identical. However, equation (24) approaches the appearance of the equations for flow in horizontal pipe lines. Equation (24) contains terms, to correct for the weight of the flowing column of gas, that are identical with those derived by Ferguson.[3]

The accuracy of equation (23) depends entirely upon the validity of the three assumptions that were made in the development. Assuming that the temperature and compressibility of the gas in the well are constant at "effective" values defines the path of the expansion in the well. Actually the temperature and compressibility of the flowing gas vary with depth in the well. If the actual path of the expansion (adiabatic, polytropic or isothermal) were known for all conditions, the development of equation (23) could be modified so that the assumptions concerning temperature and compressibility would be eliminated. The third assumption, that the kinetic energy change is negligible, is justifiable for rates of flow used in testing gas wells. However, the exact implications of this assumption may be found by solving equation (18) for a specific well problem.

Equations (23) and (24) are more covenient than equation (11) for calculating subsurface pressures in a flowing gas well but the value of the friction factor must be known before this may be accomplished.

If the rate of flow Q is zero as in a static column of gas, equation (23) and (24) reduce to the familiar equation

$$P_s^2 = e^s P_w^2 \quad \ldots\ldots\ldots\ldots (25)$$

for computing pressures resulting from the weight of a static column of gas. Thus, the equations for flowing columns of gas meet the necessary conditions that they must describe static columns of gas when there is no flow.

APPLICATION OF EQUATIONS TO A SPECIFIC WELL PROBLEM

Method I (graphic integration)

Equation (11) is particularly useful in evaluating the friction coefficient f for gas wells. Pressures and temperatures must be measured in the flowing column of gas at several depths in the well and the flow rate must be measured by suitable means to permit the application of equation (11). As the foregoing equations show, the flow mechanism in a gas well is essentially a weight-lifting process with frictional effects. Therefore, the specific-gravity term G must convert the volume of gas into the weight of the total fluid lifted in the flow. Consequently, the specific gravity term must contain all the hydrocarbon liquid and water produced during the flow. For gas wells producing hydrocarbon liquid and water, the hydrocarbon liquid: gas and the water: gas ratios must be measured so that a combined specific gravity may be computed for the flow equation.

The specific volume of the fluid at various points in the flow string may be determined in the laboratory by pressure-volume-temperature studies of the fluid or it may be calculated from published sources of information on the compressibility of natural gases. The calculation of specific volumes from compressibility factors may introduce errors unless the factors are known to apply to the fluid.

Evaluation by mathematical means of the terms containing the integral signs in equation (11) involves assumption which define the path of the integral. It is thought that the study of the actual process of expansion in a gas well is not advanced to the point where the exact type of flow, with regard to heat transfer between the fluid and its surroundings, can be defined for all conditions. In a previous section of this report an equation was developed which is based on the assumption that flow in gas wells is isothermal.

Provided pressures, temperatures and specific volumes are at hand for a given flow rate in a gas well, equation (11) may be solved for the friction coefficient by graphic integration of $\int_{P_w}^{P_s} v\,dP$ and $\int_0^L v^2 dL$. Line integral signs are used because the values of specific volume required for the integration are a function of the temperature as well as of the pressure and the relation between temperature and pressure is not specified by the terms of the integral. Solutions for similar equations applied to flow in oil wells have been given by Cattell[2] and Eilerts, Smith and Cook[4]. The graphic integration may be done with a planimeter or other suitable means.

The data necessary for evaluating the friction coefficient for a given flow rate in a gas well by means of equation (11) are illustrated in Table I.

Table I

Data Required for Graphic Integration (Method I) to Evaluate Friction Coefficients and Friction Factors For a Flowing Gas Well in the Panhandle Field, Texas

Flow Rate, M cu ft per 24 Hours	Depth to Pressure Datum Point, ft	Temperature at Pressure Datum Point, °F	Pressure at the Indicated Depth, psia	Compressibility Factor at Datum Point	Specific Volume, cu ft per lb	Specific Volume Squared, v^2
5,904	0	74.9	244.6	0.966	1.1011	1.2168
5,904	50	75.2	245.0	.965	1.1018	1.2140
5,904	1,000	80.7	251.9	.964	1.0729	1.1511
5,904	2,000	85.7	263.4	.963	1.0427	1.0872
5,904	2,250	87.0	265.8	.963	1.0359	1.0731
5,904	2,500	87.6	267.5	.963	1.0305	1.0619

d, inside diameter of flow string, in. = 5.012
G, specific gravity of gas (air = 1.0) = 0.708

The flow rate was measured with an orifice meter and computed to a pressure base of 14.4 psia and 60°F in accordance with Gas Measurement Committee Report No. 2 issued by the American Gas Association. Pressures at the various depths in the flowing column of gas were measured with an Amerada-type subsurface-pressure gage, and a recording-subsurface-temperature gage was run simultaneously with the pressure gage. The pressure-gage chart was interpreted according to

the methods proposed by Smith and Dewees.[6] Wellhead pressures were constant throughout the test and were determined with a calibrated piston gage while the subsurface-pressure gage was at each indicated depth in the well. Compressibility factors at each pressure and corresponding temperature in the well were computed from the measured specific gravity of the gas using unpublished data in the files of the Bureau of Mines. Specific volumes and the squares of the specific volumes were computed from the compressibility factors.

The specific-volume data for a flow rate of 5904 Mcf per 24 hours (14.4 psia, 60°F) of Table I were plotted against pressure as is illustrated in Fig. 1. At a depth of 2500 ft, the specific volume was 1.0305 cu ft per lb, while at the wellhead the specific volume was 1.1031 cu ft per lb. At the same time, the temperature of the gas stream decreased from 87.6°F at a depth of 2500 ft to 74.9°F at the wellhead. The area on Fig. 1 bounded by the pressure ordinates between the wellhead pressure of 244.6 psia and the pressure of 267.5 psia at a depth of 2500 ft, the dashed lines to the curve and the curve itself, when multiplied by 144 is the energy in foot-pounds expended by 1 lb of gas in moving from a depth of 2500 ft to the wellhead or

$$\text{Energy, ft-lb per lb of gas} = 144 \int_{244.6}^{267.5} v\,dP$$

The area between the indicated pressure limits may be measured with a planimeter or by any other method of approximation suitable for a finite area. For example, the area within the limits outlined above as determined with a planimeter is equivalent to 3515.8 ft-lb of energy which is used in the flowing progress to overcome frictional effects, to increase the kinetic energy of the gas as represented by a velocity change, and to lift the lb of gas from a depth of 2500 ft to the wellhead.

Equation (11) requires the evaluation of another quantity:

$$\int_0^L v^2 dL.$$

By plotting specific volume squared against depth as illustrated in Fig. 2, the quantity may be found by measuring the area between the curve and the depth ordinate within the proper depth limits. The actual measurement of the area is similar to that described in the preceding paragraph. The area on Fig. 2 bounded by the wellhead depth (L = 0) and a depth of 2500 ft was found by measurement with a planimeter to be 2839.3 units whose dimensions are volume squared times length divided by weight. Multiplication of these units by the proper quantities as indicated in equation (11) converts them to work in ft-lb.

The evaluation of the remaining terms of equation (11), the work required to lift 1 lb of gas to the wellhead and the work converted to kinetic energy requires the substitution of the proper quantities into the equation. The work necessary to lift 1 lb of gas through a vertical distance L is L ft-lb. The value of the kinetic energy term of equation (11) is found by substituting the values for the rate of flow, wellhead specific volume and specific volume at the given depth, and the inside diameter of the pipe.

The complete solution of equation (11) for the friction coefficient covering three successive depths for a flowing gas well (data presented in Table I) is given in Table II. The energy terms apply to 1 lb of gas flowing in the well. Item 1 shows the available energy for the flow process from the indicated depths to the wellhead. The energy required to lift the lb of gas to the surface and the energy used to increase the velocity of the gas are given opposite items 2 and 3, respectively. The excess of the available energy over that required to lift the gas and increase its velocity is transformed into heat by frictional effects (item 4). The remainder of the table illustrates the method of computing friction coefficients and friction factors from data on the amount of energy expended to overcome friction.

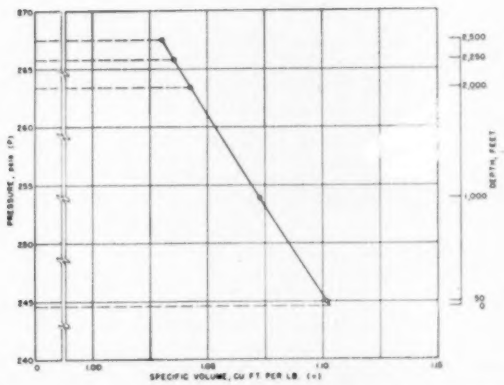

FIG. 1—GRAPHICAL EVALUATION OF ENERGY REQUIRED FOR MOVING ONE LB OF FLUID TO THE WELLHEAD FOR A FLOWING GAS WELL, $\int_{P_w}^{P_s} v\,dP$.

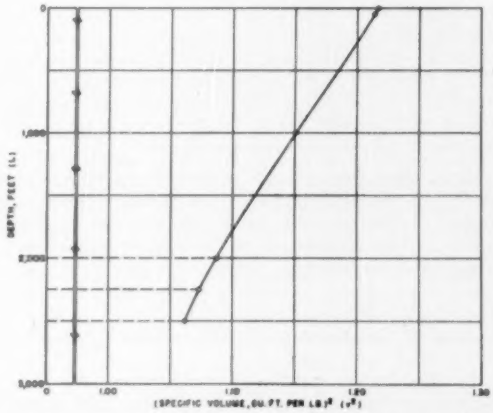

FIG. 2—GRAPHICAL EVALUATION OF THE INTEGRAL $\int_0^L v^2 dL$ FOR A FLOWING GAS WELL.

Table II

Evaluation by Graphic Integration (Method I) of Frictional Effects, Friction Coefficients and Friction Factors for a Flowing Gas Well in the Panhandle Field, Texas

Depth considered, ft	2000	2250	2500
(1) Available energy, $144 \int_{P_w}^{P_s} vdP$, ft-lb	2903.8	3,262.9	3515.8
(2) Energy to lift gas, L_w, ft-lb	2000.0	2250.0	2500.0
(3) Energy converted to kinetic energy $= \frac{Q^2G^2(v_w^2-v_s^2)}{2.5515 \times 10^{10}d^4}$ ft-lb	1.4	1.6	1.7
(4) Frictional effects $= \frac{f\,Q^2G^2}{53.157 \times 10^6 d^5} \int_0^L v^3dL$, ft-lb $=$ (1) − (2) − (3)	902.4	1011.3	1014.1
(5) $\frac{Q^2G^2}{53.157 \times 10^6 d^5}$	103.92	103.92	103.92
(6) $\int_0^L v^3dL$	2302.4	2572.5	2839.3
(7) Friction coefficient, $f = (4)/(5) \times (6)$, dimensionless	0.003772	0.003783	0.003437
(8) Friction factor, $\sqrt{\frac{1}{f}}$, dimensionless	16.28	16.26	17.06

Note: Well was flowing at the rate of 5904 Mcf per 24 hours (14.4 psia, 60°F) through a 5.012 in. inside diameter flow string.

The percentage distribution of the available energy among friction, lifting, and velocity increase is shown in Table III. For this particular well producing gas through a 5.012-in.-inside-diameter flow string at a rate of 5904 Mcf per 24 hours approximately 30 per cent of the available energy was consumed in overcoming friction; the remaining 70 per cent was used to lift the gas to the wellhead, and 0.05 per cent of the energy was used to increase the velocity of the gas. In comparison with frictional effects and lifting requirements the loss due to velocity increase was negligible.

The difference between frictional effects as reflected by energy, friction coefficient or friction factor as shown in Table II for the same flow rate in the same well but from different depths probably can be attributed to errors in the measurement of pressure.

Method II (mathematical integration)

Equation (23), (or equation (24)), which was obtained by mathematical integration of the energy-balance relationships is in convenient form for computing friction factors for flowing gas wells if the flow rate and the pressure at a given depth in the well is known.

Table III

Distribution of Available Energy for a Flowing Gas Well in the Panhandle Field, Texas

Distribution of Energy	Per Cent for Flow from Indicated Depths, ft		
	2,000	2,250	2,500
Lifting	68.87	68.96	71.11
Kinetic	.05	.05	.05
Frictional effects	31.08	30.99	28.84
Total or available energy	100.00	100.00	100.00

Employing the same data presented previously to illustrate the use of Method I, with estimated effective temperatures and compressibilities, friction factors may be computed by means of equation (23). The required data are illustrated in Table IV, which contains part of the data presented previously in Table I. In addition, Table IV shows effective temperatures and compressibilities estimated for the flowing column of gas to the indicated depths.

Exact methods of estimating the effective temperature and compressibility to describe adequately the behavior of a column of gas are not known. If the temperatures measured at different depths in the flowing well (Table I) are plotted as a function of depth on regular coordinates, a curve is obtained which changes from a straight line near the surface to a curved line at the lower depths. The values of effective temperatures presented in Table IV were obtained by determining the area within the limits of zero depth and the depth under consideration between the depth-temperature curve and a given reference temperature; the measured area was then divided by the specific depth under consideration to obtain an effective temperature.

Table IV

Friction Factors and Data Required for Their Computation by Mathematical Integration (Method II) for a Flowing Gas Well in the Panhandle Field, Texas

Flow Rate, M cu ft per 24 Hours	Depth to Pressure Datum Point, ft	Pressure at Indicated Depth, psia	Effective Temperature to Depth, °F	Effective Compressibility to Depth, Dimensionless	Friction Factor, $\sqrt{\frac{1}{f}}$ Dimensionless
5,904	0	244.6			
5,904	50	245.0			
5,904	1,000	253.9			
5,904	2,000	263.4	80.7	0.964	16.27
5,904	2,250	265.8	81.3	.964	16.25
5,904	2,500	267.5	82.0	.964	17.05

d, inside diameter of flow string, in. = 5.012
G, specific gravity of gas (air = 1.0) = 0.708

Other methods of arriving at an effective temperature have been devised but the superiority of any one method is not known.

The effective compressibilities given in Table IV are those computed for the gas under pressure and temperature conditions at the midpoint of the flowing column of gas.

Substitution of the data shown in the first five columns of Table IV, with the values of the inside pipe diameter and the specific gravity of the gas, into equation (23) permits calculating the friction factor shown in the last column of Table

IV. For example, after substituting the values given for the depth of 2500 ft in Table IV into equation (23), the friction factor may be computed by completion of the indicated arithmetical operations in the following expressions:

$$s = \text{exponent of } e = 0.037504 \frac{.708 \times 2500}{.964 \times 541.6}$$

$$s = 0.12714$$

$$e^s = e^{.12714} = 1.1356$$

$$5,904,000 = 19,686 \left(\frac{1}{.964 \times 541.6} \right) \sqrt{\frac{1}{f}}$$

$$\sqrt{5.012^2 \left(\frac{267.5^2 - 1.1356 \times 244.6^2}{1.1356 - 1} \right)}$$

or $$\sqrt{\frac{1}{f}} = 17.05$$

Values of the number e raised to powers may be taken from mathematical tables, computed with logarithms or calculated by means of the infinite series:

$$e^s = 1 + s + \frac{s^2}{2} + \frac{s^3}{6} + \frac{s^4}{24} + \ldots \ldots$$

Previously, friction factors for the same depths and basic data were computed by Method I, involving graphic integration, and were presented in Table II. Friction factors computed by Methods I and II and shown for comparison in Table V indicate that by either method virtually identical results are obtained. Data shown in Table V indicate for the given example that the estimation of effective temperatures and compressibilities by Method II gives accurate results.

The friction factors, presented in Table V, agree closely for depths of 2000 and 2250 ft but have a much higher value for a depth of 2500 ft; the difference probably is the result of error in pressure measurement at a depth of 2500 ft. Present-day knowledge of friction factors for gas wells is too limited to permit conclusions as to the accuracy of data shown in Table V, which are presented only to show the close agreement of friction factors calculated by two different methods.

Table V

Friction Factors Computed by Method I (Graphic Integration) for a Flowing Gas Well in the Panhandle Field, Texas

Flow Rate, M cu ft per 24 Hours	Depth Considered, ft	Friction Factors	
		Method I	Method II
5,904	2,000	16.28	16.27
5,904	2,250	16.26	16.25
5,904	2,500	17.06	17.05

SUMMARY

Two methods of calculating friction factors from data taken on flowing gas wells are presented in this report. Method I, which requires flowing pressures and temperatures at several points in the flowing gas stream, provides a solution for the energy-balance equation by graphic integration over the actual path of the expansion of the fluid in the well. In Method II, the energy-balance equation is integrated mathematically, the assumption having been made that the flow in a gas well is isothermal and at a constant compressibility, even though the temperature and compressibility of the fluid vary through wide limits.

The graphic integration of the energy-balance equation (Method I) provides a means of determining the energy available for lifting the fluid from the well and overcoming friction as the integration follows the expansion of the fluid along the path determined by temperature, compressibility and phase changes. Thus, condensation of liquids and wide variations in temperature and compressibility are taken into account without the necessity of making assumptions that may or may not apply. Method I, therefore, is particularly applicable in calculating friction factors for deep high-pressure and high-temperature gas wells.

The accuracy of Method I depends upon the efficiency of the graphic integration. The curves, illustrated by Fig. 1 and 2, should be plotted on suitable coordinates so that the areas are large enough to permit accurate measurement with a planimeter. If a planimeter is not available, one of several methods of estimating areas may be used.

The mathematically integrated equation (Method II) assumes a definite path for the expansion of the fluid in the well with both the temperature and the compressibility fixed at constant values. Its accuracy depends upon the degree to which the effective temperature and compressibility approximate conditions in the well. Method II provides a convenient and practical method for calculating friction factors from data on flowing gas wells and lends itself readily to the calculation of subsurface pressures in a flowing gas well which cannot be accomplished by Method I.

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DISCUSSION

By C. W. Binckley, Phillips Petroleum Co., Bartlesville, Okla.:

The vertical flow equation developed by Smith in his paper and described as equation (24) is the equation generally used to compute bottom-hole flowing pressures in gas and condensate wells. In the use of the equation, it is necessary to first obtain friction factors, an effective temperature factor of the gas stream and an effective compressibility factor. The accuracy of the computed bottom-hole working pressures is primarily dependent upon the accuracy of the friction factors and the validity of the methods used to determine the effective temperature and effective compressibility factors.

Several engineers have recently attempted to develop a general vertical flow equation for gas in which the temperature and compressibility are included as functions of depth and pressure. Such an equation could be used to compute bottom-hole flowing pressures by application of suitable friction factors. An equation of this nature has not been published and I do not believe one has been developed in a usable form.

Smith gives us a different approach to the problem. He describes a graphic integration method for determining friction factors by use of well test data. He then proceeds to show that by use of the general vertical flow equation, assuming an effective compressibility and temperature found at the midpoint of the flowing gas column, that a very close check is obtained for friction factors determined by the equation and by the graphic integration method. The check on friction factors was obtained by using data taken on a well with a relatively low pressure and low temperature flowing gas column.

The application of the procedures described in the paper to the determination of effective compressibility for high temperature and pressure gas columns of wells is not discussed by the author. This is an important point in improving the results of computed bottom-hole flowing pressures. For example, the graphic integration method can be used to establish friction factors. The friction factors can be used in connection with the general vertical flow equation and temperature gradient data to establish the effective compressibility. If the nature of the effective compressibility can be ascertained, we will have a better approach to the computation of reliable bottom-hole flowing pressures. In fact computed pressures should be as reliable as those measured with the bottom-hole pressure gage.

Furthermore, by proper correlation of experimentally determined friction factors with Reynolds numbers or other indexes and by use of a method for determining effective compressibility, it is probable that accurate bottom-hole flowing pressures can be established for all wells in a field by obtaining basic test data on a few representative wells. ★ ★ ★

PERFORMANCE CHARACTERISTICS OF A VOLUMETRIC CONDENSATE RESERVOIR

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ABSTRACT

The performance history of a volumetric gas condensate reservoir is presented. Curves depict the pressure-production relation and illustrate the phase behavior of the reservoir fluid. This performance is compared to calculated performance.

This Bacon Lime Reservoir was discovered in 1941 and has been produced to field separators and gas sales. Reservoir performance has been observed by periodic bottom hole pressure surveys and companion sample analysis of well effluents, in addition to gas and condensate production data.

The pressure-production history demonstrates that the reservoir has produced under volumetric control. The "retrograde" behavior of the reservoir fluid is illustrated by decreasing butanes-plus content of the well effluent, followed by revaporization as the reservoir pressure approaches abandonment. Calculated performance predictions are compared to actual performance and some discussion offered on apparent discrepancies.

INTRODUCTION

Since the late 1930's, many gas condensate re ervoirs have been developed, the retrograde theory of phase behavior has been generally accepted, and a number of cycling programs have been initiated. Numerous technical papers have since appeared in the literature dealing with the theory and application of cycling the gas condensate reservoirs. Some cycling operations have now advanced to a stage where it is possible to determine performance characteristics to a fair degree of accuracy.

Field performance data for gas condensate re ervoirs operated by pressure depletion have not been so extensively reported in the literature, although their probable behavior has been discussed in explanation of the retrograde theory. It is the purpose of this paper to compare calculated theoretical reservoir performance with field observations and well stream analyses which have been obtained throughout the practical producing life of a small volumetric gas condensate reservoir.

The reservoir under study is the Bacon Lime Zone of a field located in East Texas. The Bacon Lime occurs in the Lower Glen Rose Formation of Cretaceous Age. This Bacon Lime Reservoir is encountered at an average depth of 7600 ft (7200 ft subsea elevation) and comprises approximately 3100 acres located on a structural high with 80 ft of productive closure. The producing formation consists of approximately 50 ft of dense crystalline fossiliferous dolomite of generally low permeability with typical wide variation in both permeability and porosity, the more permeable stringers measuring 30 to 40 millidarcys. The average porosity is estimated to be 10 per cent with a connate water saturation of approximately 30 per cent of the pore space. The reservoir temperature was found to be 220°F and the original pressure was 3691 psia at -7200 ft elevation.

The reservoir was discovered in November, 1941, and is now essentially depleted. Throughout most of its productive life, from the standpoint of cumulative withdrawals, the reservoir has been produced by five wells. During its latter stages of depletion, 16 wells were completed in the Bacon Lime.

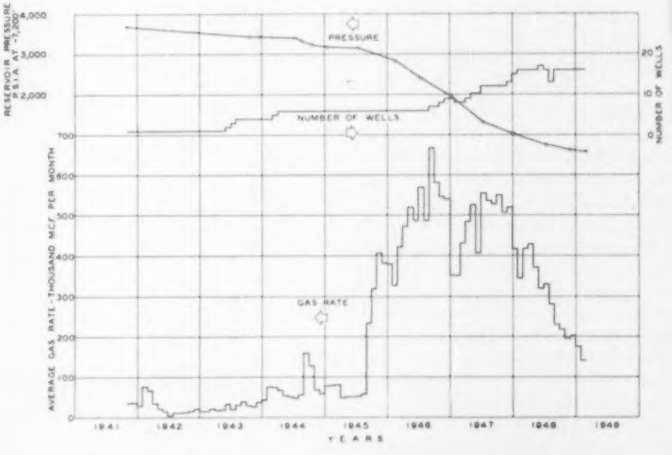

FIG. 1 — BACON LIME CONDENSATE RESERVOIR, RESERVOIR PERFORMANCE.

[1] References are given at end of paper.

Manuscript received at the office of the Petroleum Branch October 3, 1949. Paper presented at the Petroleum Branch meeting in San Antonio, October 5-7, 1949.

Remarkably poor communication has been observed between the wells producing from this zone. Early in the life of the reservoir, it was concluded that it would not be feasible to attempt cycling or pressure maintenance in this small reservoir. The reservoir has, therefore, been produced by pressure depletion with three-stage separation. The first separator has been operated at approximately 500 psig throughout most of the producing life of the reservoir and the second or intermediate stage at 40 psig. The estimated ultimate recovery by this means is in excess of 21,000,000 Mcf of gas and 850,000 bbl of condensate. The production history of the reservoir is shown in Fig. 1.

The initial composition of the reservoir fluid, based upon analyses of companion samples which were obtained from the discovery well soon after its completion, was determined to be as follows:

Table I

Initial Composition of Reservoir Fluid

	Mol Fraction
Methane	0.7693
Ethane	0.0770
Propane	0.0335
Butanes	0.0350
Pentanes	0.0210
Hexanes	0.0150
Heptanes - plus	0.0360
Carbon Dioxide	0.0135
	1.0000

Heptanes - plus:
Mol Wt 130
Sp Gr 0.7615

CALCULATED THEORETICAL PERFORMANCE

Employing this initial composition and the vaporization equilibrium constants of Roland, Smith and Kaveler[1] corrected to a convergence pressure of 4200 psia at 220°F, the theoretical performance of the reservoir was calculated under the two separate assumptions of flash and differential vaporization. These are comparable to two methods under which laboratory cell experiments are normally conducted in investigations to determine the changes which will occur in the composition of the production from a volumetric condensate reservoir during its depletion. The vaporization equilibrium constants which were used in these calculations

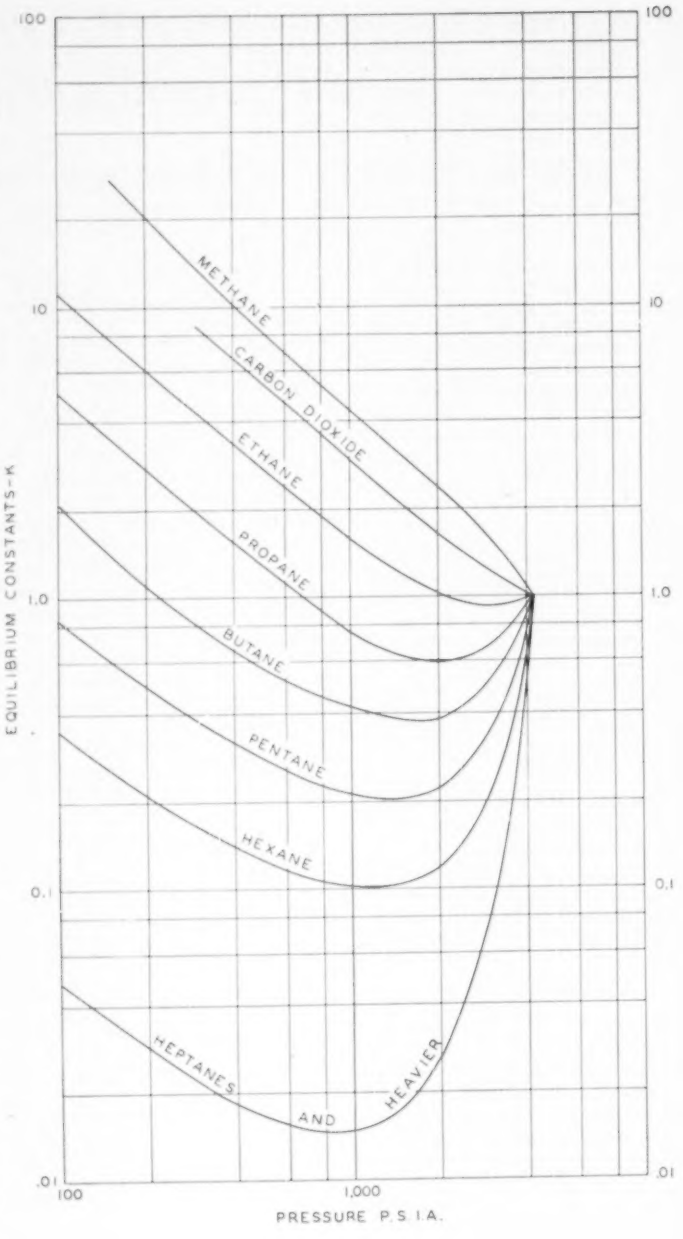

FIG. 2 — BACON LIME CONDENSATE RESERVOIR, VAPORIZATION EQUILIBRIUM CONSTANTS, RESERVOIR TEMPERATURE 220°F.

are shown plotted against pressure in Fig. 2. The constant for the Heptane-plus fraction was estimated, taking into account its reported molecular weight and specific gravity. The two types of estimated performance calculations are illustrated graphically in Fig. 3. The flash vaporization calculations were accomplished by assuming a constant composition of the whole system and computing the composition and volumes of each phase which resulted at successive reductions in pressure. The differential vaporization calculations were made by flashing the original composition to the first pressure from which the compositions and volumes of the two phases were computed. The volume of the vapor phase which it was necessary to produce in order to maintain a constant volume was then calculated and the number of mols of each component in the vapor represented by this volume was subtracted from the system. This resulted in a new over-all composition which was then flashed to the second or next lower pressure. This series of calculations representing differential vaporization assumed that only the vapor phase was produced from the reservoir with no flow, or production of the liquid phase. The resulting variations in composition of the vapor phase which was assumed to represent the composition of the well stream during the decline in reservoir pressure under both these methods of calculated theoretical performance are shown in Fig. 4. The two methods of calculation indicate the same well stream composition until the reservoir pressure drops to approximately 1500 psia after which differential vaporization produces greater revaporization of the ethane through hexanes components than is obtained from the flash vaporization process. Both vaporization processes indicate significant revaporization of the heavier components at reservoir pressures below 1200 psia. The pressure at which revaporization commences for each component varies progressively from approximately 3000 psia for ethane to about 1400 psia for the heptanes-plus fraction.

Gas deviation factors determined from reduced temperature and pressure correlations shown in Fig. 5 indicate essentially no difference in compressibility of the vapor phases obtained from the differential and flash vaporization proc-

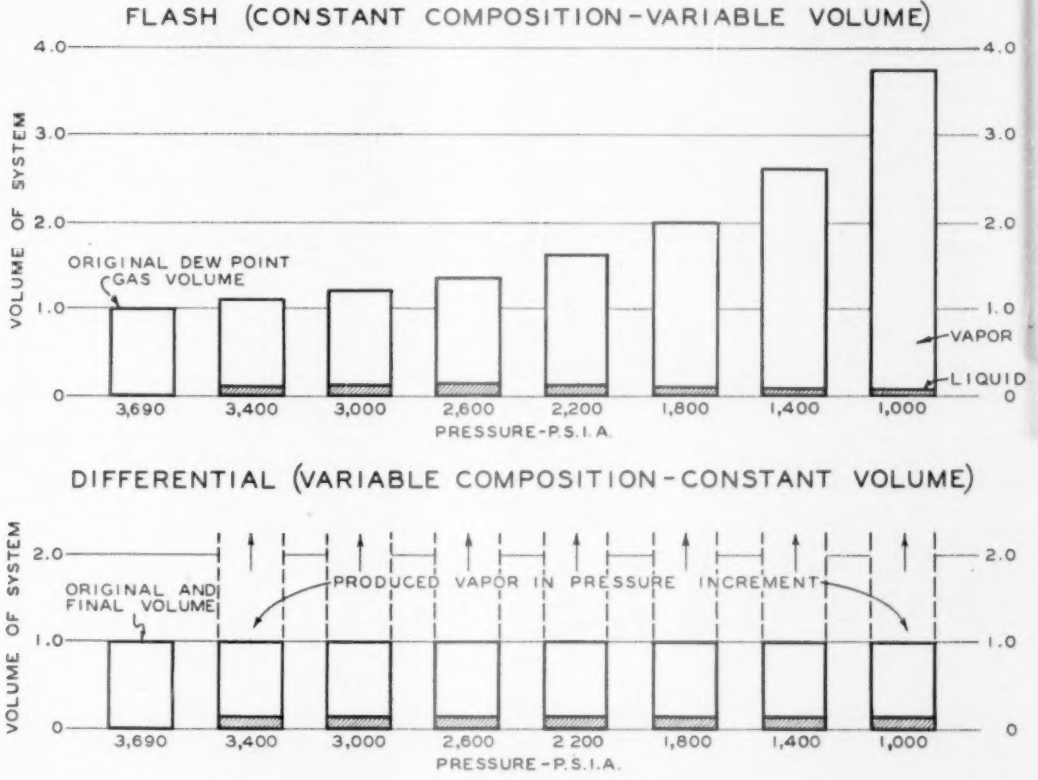

FIG. 3 — BACON LIME CONDENSATE RESERVOIR, METHODS OF CALCULATING THEORETICAL RESERVOIR PERFORMANCE.

esses. The calculated compressibility of the vapor phases, with and without retrograde condensation, differ markedly. The pressure reduction versus cumulative gas production relationship was practically identical for the two vaporization processes. The specific volumes calculated for the two phases as illustrated by Fig. 6, give some idea of the similarity of properties of the two phases at high pressures. Again, the difference in the two computations is demonstrated by different values of vapor specific volumes at the lower pressures. Definite variation in the volumes of liquid condensed by the two vaporization processes was computed as shown in Fig. 7. The reservoir fluid was indicated to be at its dew point initially.

A qualitative indication of the phase envelope based on the estimated original critical point and the upper dew point of the initial reservoir hydro-carbon system, and the liquid volume saturations at reservoir temperature as indicated from the flash vaporization process is shown in Fig. 8. It is of interest to note the changes which occur in the critical point and the upper dew point of the remaining reservoir hydrocarbon fluids at reservoir temperature as the pressure depletion progresses under differential vaporization.

OBSERVED RESERVOIR PERFORMANCE

The calculated performance of reservoir pressure decline with cumulative gas withdrawals, with and without correction for gas compressibility factors, is plotted in Fig. 9. Points represent average reservoir pressures obtained from field pressure surveys. Gas withdrawals have been converted to a wet gas basis and most pressures were obtained by bomb after a minimum of 48-hour shut-ins. Good agreement was obtained on most surveys in view of the apparent lack of communication between individual wells. A "best line" through the points indicates the actual pressure production trend to be leveling out slightly and is interpreted as being production from extremely tight portions of the reservoir rock. The same figure shows the recovery rate of stock tank liquid condensate and indicates no substantial increase in liquid recovery rate due to revaporization at the lower reservoir pressures.

Companion samples of the well stream from two wells and reservoir pressure measurements from several wells were obtained at intervals of six months throughout the productive life of the reservoir. The pressure measurement and sampling interval was reduced to three months during the latter stages of the reservoir depletion. The compositions of the well stream which were obtained from this series of sample analyses are indicated in Fig. 10. It will be noted that in the main, the observed changes in composition of the well stream during the depletion of the reservoir conformed reasonably well with the theoretical compositions reported in Fig. 4. The observed variation in molecular weight and specific gravity of the heptanes-plus fraction of the

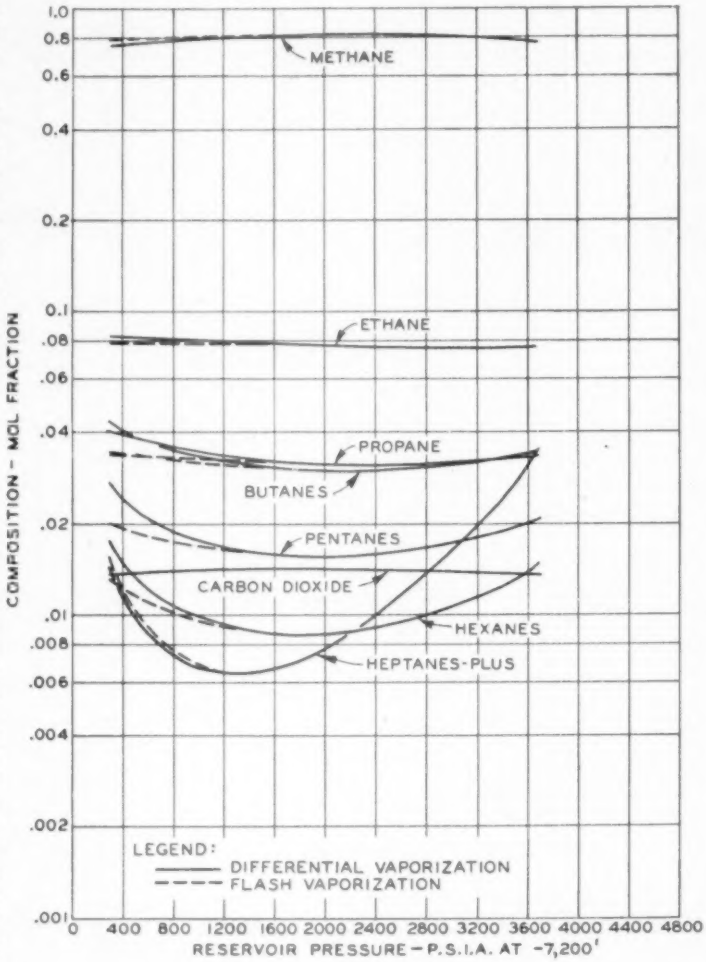

FIG. 4 — BACON LIME CONDENSATE RESERVOIR, CALCULATED THEORETICAL COMPOSITION OF WELL STREAM DURING PRESSURE DEPLETION.

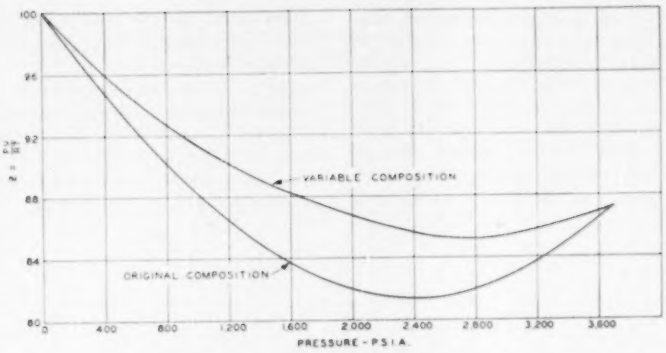

FIG. 5 — BACON LIME CONDENSATE RESERVOIR VAPOR PHASE COMPRESSIBILITY FACTORS.

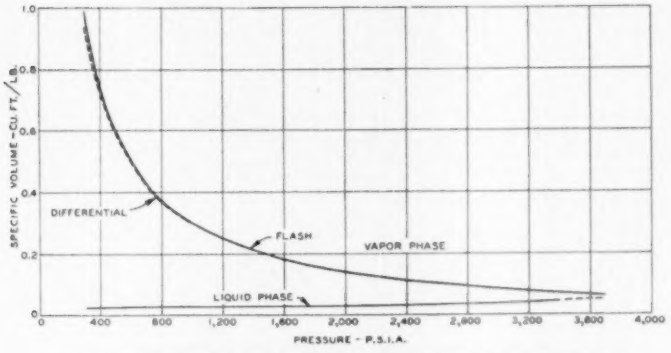

FIG. 6 — PHASE SPECIFIC VOLUMES 220°F, FLASH AND DIFFERENTIAL CALCULATIONS.

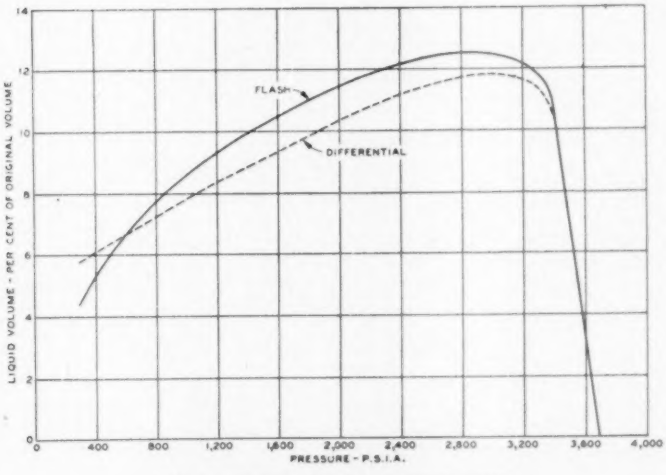

FIG. 7 — VOLUMES OF LIQUID CONDENSED, 220°F.

well stream which occurred during the productive life of the reservoir are indicated in Fig. 11. This variable nature of the heptanes-plus fraction was not considered in making the theoretical calculations.

Of principal interest in an economic analysis of condensate reservoir performance is the concentration of the butanes-plus fraction which occurs in the produced well streams throughout the depletion of the reservoir. The observed history of the butanes-plus concentration in the produced well streams as indicated from the series of companion samples is plotted in Fig. 12. These data illustrate definite revaporization of these fractions from the condensed liquid in the reservoir. This increase was not reflected in stock tank liquid recovery, however, as illustrated in Fig. 9. Superimposed on these data is the butanes-plus concentration which was calculated under the two assumptions of differential and flash vaporization. It was found that the early life of the reservoir is characterized by substantially higher concentration of butanes-plus in the well stream analyses than was predicted under the calculated theoretical performance. Theoretical calculations show that 54 per cent of the original butanes-plus material should be produced down to a reservoir pressure of 600 psia. Allowing for normal separator recovery factors, the cumulative stock tank recovery would be 1.54 GPM compared to initial recovery of 3.50 GPM. Actually, the cumulative stock tank recovery to 600 psia has been 1.70 GPM as compared to an initial average recovery of 3.60 GPM.

COMPARISON OF ESTIMATED AND ACTUAL RESERVOIR PERFORMANCE

Several possible interpretations have been proposed for the variation between the observed and the theoretical estimated reservoir performances which are most evident in Fig. 12. One of these lies in the possibility that the initial companion samples were not entirely representative of the original reservoir fluid due to the pressure draw-down which was required for production during the sampling operations. This might have resulted in condensation around the well bore to produce a well effluent,

which was unduly rich in the lighter hydrocarbons. A second possible explanation is derived from the fact that small amounts of nitrogen, never in excess of one mol per cent, have been picked up in several of the sets of companion samples during the life of the reservoir. Nitrogen was not included in the original analysis of the reservoir fluids nor taken into account in the calculations. It is conceivable that the nitrogen exerted a depressing effect on the methane volatility which was not taken into account in the calculations. This effect may be discounted somewhat by the probably opposite effect nitrogen would have on the convergence pressure and thus on the equilibrium constants for the other components. An adjustment in the constant for the heptanes-plus fraction to account for its changing properties would tend to give a smaller calculated GPM content in the well stream.

A more likely interpretation, however, of the discrepancy between the observed and the estimated theoretical performance seems to be that liquid condensate was flowing into the well bore throughout most of the life of the reservoir which resulted in increasing the observed GPM of the well stream. Following this hypothesis, an approximate Kg/Ko relationship was estimated by assuming that the difference between the observed and calculated GPM values shown in Fig. 12 was produced from the reservoir formation as a liquid. The liquid hydrocarbon saturations obtained from the differential vaporization calculations were considered to be uniform throughout the reservoir rather than concentrated in the vicinity of the well bore. A connate water saturation of 30 per cent of the reservoir pore space and a constant gas-liquid viscosity ratio of 1:20 were employed in determining these approximate Kg/Ko relationships. The results of these calculations are shown in Fig. 13 along with several laboratory gas-oil relative permeabilities which have been reported in the literature. The estimated Kg/Ko relationship for the Bacon Lime Reservoir falls well within the range of the previously reported experimental data and closely approximates the limestone relative permeability relationships reported by Bulnes and Fitting[2] except for the steeper slope of the approximated Bacon Lime Kg/Ko curve. It must be recognized, however, that neither of the calculated reservoir performances assumed the possibility of the production of liquid condensate from the reservoir. Liquid condensate production would result in a progressive reduction in the reservoir liquid hydrocarbon saturation which should, in turn, decrease the slope of the approximate Kg/Ko curve shown on Fig. 13. This effect would, of course, be limited by the equilibrium saturation for liquid flow.

This part of the relative permeability relationship representing liquid saturations just in excess of the equilibrium value for liquid flow has not been emphasized in laboratory measurements of relative permeability relationships to

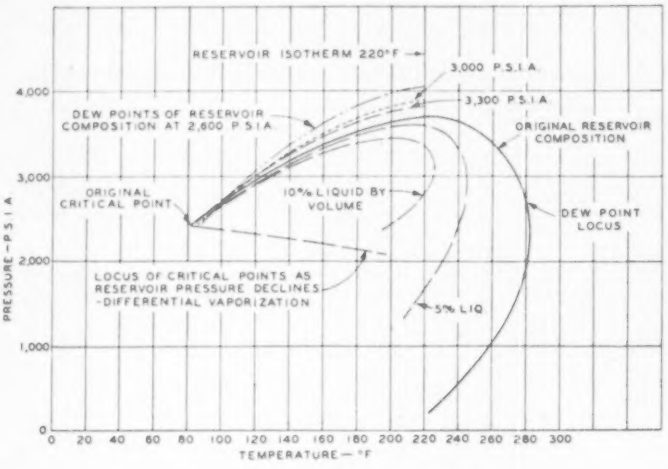

FIG. 8 — OUTLINE OF PHASE DIAGRAM CONSTANT AND VARIABLE COMPOSITION.

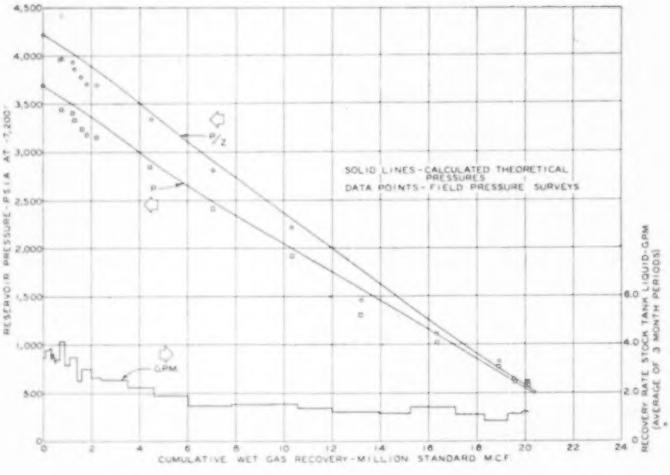

FIG. 9 — BACON LIME CONDENSATE RESERVOIR, RESERVOIR PERFORMANCE.

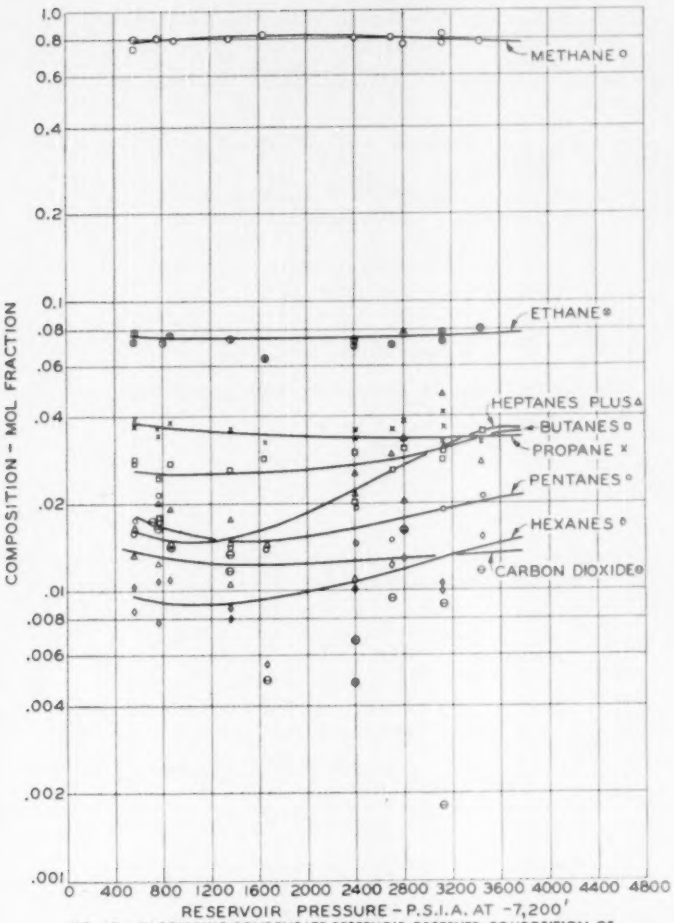

FIG. 10 — BACON LIME CONDENSATE RESERVOIR OBSERVED COMPOSITION OF WELL STREAM WITH PRESSURE DEPLETION.

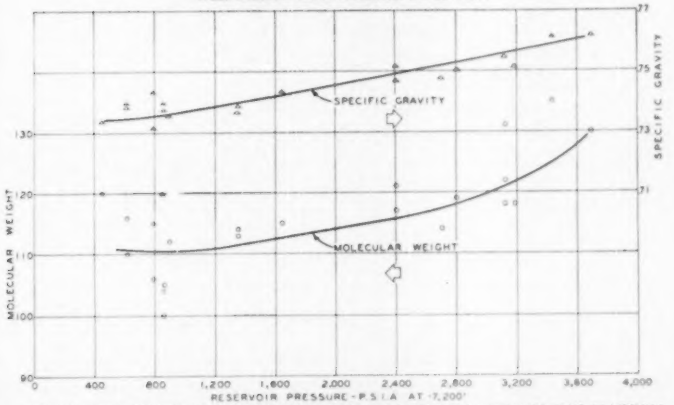

FIG. 11 — BACON LIME CONDENSATE RESERVOIR PROPERTIES OF HEPTANES PLUS FRACTION FROM OBSERVED WELL STREAM ANALYSES.

the same extent as the other end of the curve which includes the total liquid saturations in the vicinity of the equilibrium saturation for gas flow. Neither has it been possible to derive gas-oil relative permeability relationships in the region of the equilibrium point for liquid flow from actual field data. The availability of such gas-oil relative permeability data would make it possible to reverse the train of calculation from which the Kg/Ko relationship reported in Fig. 13 was derived and thus obtain an estimate by means of theoretical calculations of the flow rates of both gas and condensate from the formation and resulting enrichment of the well stream compositions. Reservoir performance predictions computed in this manner would closely reproduce the observed changes in composition of the production which occurred during the pressure depletion of the Bacon Lime Reservoir.

SIGNIFICANCE OF OBSERVED PERFORMANCE INDICATING CONDENSATE REVAPORIZATION

Although the data from actual companion samples of the produced well stream reported in Fig. 12 indicate definite revaporization of the heavier hydrocarbon components, no conclusive evidence of increased recovery of these fractions is indicated by the condensate recovery curve shown in Fig. 9. This lack of increased recovery due to revaporization during the final stages of depletion is apparently due to the low level of separator efficiency at these conditions. In the particular reservoir under study, the temperature of the high pressure separator gas increased steadily, with seasonal fluctuation, as reservoir pressure declined and is presently 40°F higher than those originally observed. This increase in separator temperature with decreasing reservoir pressure is interpreted as the result of decreasing effectiveness of Joule-Thomson cooling as the well production is flashed in the high pressure separator. At optimum separation pressures the liquid condensate recovery from stage separation is a direct function of the separation temperatures. It is, therefore, concluded that revaporization was taking place in the formation during the latter stages of depletion of this Bacon

Lime Condensate Reservoir, but the efficiency of the conventional three-stage separation system had declined to a level which prevented any significant additional recovery of liquid hydrocarbons from the revaporization process.

SUMMARY AND CONCLUSIONS

Predicted theoretical performance for a small volumetric condensate reservoir has been calculated on the two assumptions of flash and differential vaporization. The results of these calculations have been compared with observed performance determined from companion samples obtained throughout the producing life of the reservoir. It is concluded that the principal discrepancy between the computed and observed performance was due to the flow of liquid condensate from the formation which enriched the GPM of the well streams throughout most of the productive life of the reservoir. Revaporization of condensed liquids is indicated by the data representing the latter stages of reservoir depletion. It is evident, however, that the low level to which separator efficiency had declined by the time revaporization of the heavier hydrocarbons became appreciable prevented taking definite advantage of this increased GPM of the well streams.

ACKNOWLEDGMENT

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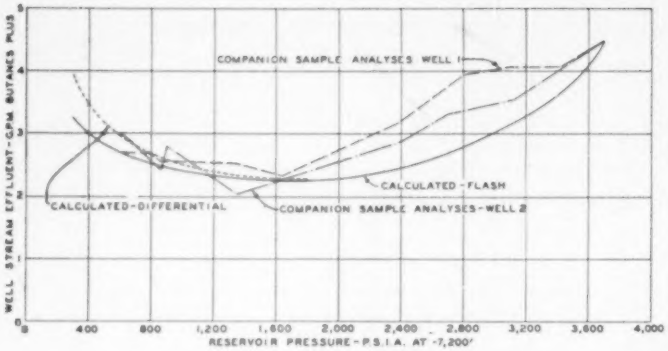

FIG. 12 — BACON LIME RESERVOIR WELL STREAM COMPOSITION.

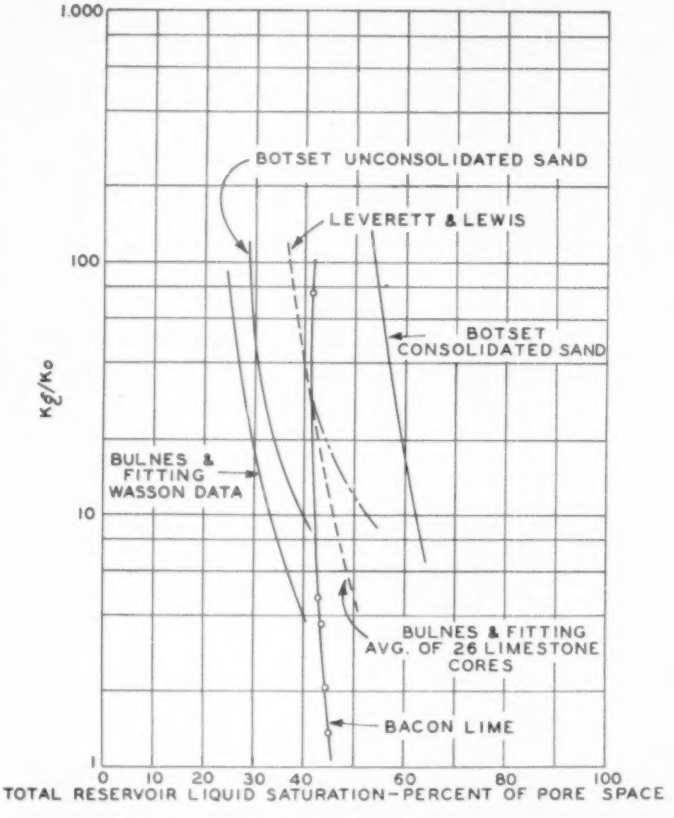

FIG. 13 — BACON LIME CONDENSATE RESERVOIR GAS OIL RELATIVE PERMEASILITY RATIOS.

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